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ABSTRACT

This project was conducted to determine the vocational, technical, and scientific skills and knowledge needed to work with the fiber optics applications that are in all areas of technology. A research assistant was hired by the project director to collect data and develop a research base for the project. Information was gathered through a combination of written and verbal contact with members of industry, examination of current research, and analysis of the learning required for the field of fiber optics. As a result of the research, a three-course curriculum (252 hours) outline was developed for Bergen County Vocational-Technical School (New Jersey). The curriculum was based on analysis of typical job responsibilities in the field, and noted a distinction between learning that required college-level preparation and learning that could be presented in a technical education environment. The report includes the curriculum guide for the three courses (Introduction to Modern Electronic Communications, Modern Electronic Communications II, and Introduction to Fiber Optics and Lasers) and an extensive bibliography. (KC)

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FINAL REPORT

OF

"Research in Fiber Optics: Implication for Fiber Optics in Vocational-Technical Education"

1984-85

Bergen County Vocational-Technical School
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Henry Van Kooy

Project Researcher
Srimat-Tirumata Chakrader

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Members of the Board of Education of the Vocational School in the County of Bergen.

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PROJECT TITLE: Resource Development for Laser-Fiber Optics Tech.
LEGAL NAME OF APPLICANT,
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ABSTRACT

DESCRIPTION OF PROJECT

(Use this sheet and no more than one other to type in single-spaced form a statement of project objectives, procedures to be followed, state and local priorities emphasized and the expected contribution of the project to vocational education.)

OBJECTIVES:

The primary goal of this project was to determine the vocational, technical and scientific skills and knowledge needed to work with the fiber optics applications that are in all areas of technology. Applications exist in medicine, surgery, cancer treatment, surface measurements on machined parts, pH detectors, communications, gas flame analysis, recording discs, and in the supermarket to read the price of packaged goods at the checkout counter. Toward this primary goal, the following objectives were set forth:

(a) To describe state state-of the art developments in fiber optics technology;

(b) To review and evaluate applications of the technology, as well as fiber optics industries, in order to provide practical approaches for teaching this technology at the vocational-technical level;

(c) To prepare an appropriate curriculum which included support equipment, appropriate mathematics and learning experiences in the areas of the physics of optics, electronic communications and fundamental semiconductor technology.

PROCEDURES:

A research assistant was hired by the project director to collect data and develop a research base for this project. Information for this project was gathered through a combination of written and verbal contact with members of industry, examination of current research and analysis of the learning required for the field of fiber optics. A detailed study ensued, involving both domestic and foreign research. A three-course curriculum (252-hours) outline evolved from the research, from analysis of typical job responsibilities in the field, and from a distinction made between learning that required college level preparation and learning that could be addressed in a technical educational environment.

CONTRIBUTION TO EDUCATION:

This project addressed state and local priorities for modernization and improvement of vocational education through high technology curricula. In addition, fiber optics technology can be used with mathematics and with mechanical, electrical, chemical and electronic technologies, thus providing a broad range of applications for education.

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DEFINITION OF TERMS

AMPLIFIER: A device used to increase the voltage, current or power of an electrical signal by means of an active device such as a transistor or electron tube.

AMPLITUDE: The maximum instantaneous value of an alternating voltage or current. Peak value.

ANALOG: A measurable quantity that takes on a continuous set of values. Non digital.

ATTENUATION: The diminution of signal amplitude or power. Attenuation is generally expressed in db/km.

ATTENUATION LIMITED OPERATION: The condition prevailing when the signal amplitude (rather than the distortion) limits the communciation capacity.

AVALANCHE PHOTODIODE: A photodiode designed to take advantage of avalanche multiplication of photocurrent.

AXIAL RAY: A light ray that travels along the optical axis.

BACKSCATTERING: The scattering of power into the direction opposite the signal transmission.

BANDWIDTH: The range of frequencies over which the output of a device does not drop by more than 70.7% below its maximum output.

BANDWIDTH LIMITED OPERATION: The condition prevailing when the frequency spectrum or bandwidth, rather than the amplitude of the signal, is the limiting factor in communication capability.

BARRIER LAYER: In an optical waveguide, a localized minimum in refractive index in the region of the core and cladding interface.

BASEBAND RESPONSE FUNCTION: Synonym for transfer function.

BEAM DIVERGENCE ANGLE: Half the vertex angle of the cone that encompasses a circle of a diameter equal to the beam diameter at all points in the far field.

BEAMSPLITTER: A device for dividing an optical beam into two or more separate beams.

BEAM SPREAD: The angle between two planes, within which passes a specified fraction of the total power in an optical beam.

BEAMWIDTH: The linear dimension of the region over which the beam irradiance falls within specified limits.

BIAS: The application of a voltage or current to an active device to produce a desired mode of operation, such as in the linear region for an amplifier.

BIREFRINGENT MEDIUM: A material that exhibits different indices of refraction for orthogonal linear polarizations.

BLACKBODY: A total absorbing body (that reflects no radiation).

BOLTZMAN'S CONSTANT: A constant that relates the average energy of a molecule to the absolute temperature of the environment.

BOUND MODE: A propagating mode whose power is predominantly in the core of the waveguide.

BREWSTER'S ANGLE: For light incident on a plane boundary between two regions having different refractive indices, that angle of incidence at which the reflectivity of light having its electric field vector in the plane defined by the direction of propagation and the normal to the surface is zero.

BRIGHTNESS: An attribute of visual perception, in accordance with a source which appears to emit more or less light.

CHIRPING: A rapid change (as opposed to long term drift) in the emission wavelength of an optical source. Chirping is most.often observed in pulsed operation of a source.

CHROMATIC DISPERSION: Redundant synonym for dispersion.

CIRCUIT: An interconnection of components to form a complete path for the flow of electrical current.

CLADDING: In an optical waveguide, a homogenous dielectric that concentrically surrounds the core with a lower refractive index.

CLADDING MODE: A propagating mode whose power is predominantly in the cladding.

COHERENCE AREA: The area in a plane perpendicular to the direction of propagation over which light may be considered highly coherent.

COHERENT: Characterized by a fixed phase relationship among points on an electromagnetic wave.

COLLIMATION: The process by which a divergent or convergent beam of radiation is converted into a beam with the minimum divergence possible.

CORE: The center region of an optical waveguide through which is intended that light be transmitted.

CORE DIAMETER: The diameter of the waveguide at the point where the refractive index of the core exceeds that of the cladding by a certain constant times the difference between the maximum refractive index in the core and the minimum refractive index in the cladding.

COUPLING LOSS: The power loss suffered when coupling light from one optical device is transmitted to another.

CRITICAL ANGLE: When light propagates in a homogenous medium of relatively high refractive index toward a planar interface with a homogeneous material of lower index, the critical angle of incidence is defined as the angle of incidence at which total internal reflection occurs.

DECIBEL: A logarithmic unit used to show the power or voltage gain of an amplifier or the attenuation of a filter.

DIGITAL: A nonlinear process in which a variable takes on discrete values.

DIODE: An electronic device that allows current to flow through it in only one direction.

DISSIPATION FACTOR: An indication of how much power is dissipated in a capacitor or a coil at a given frequency.

DISTORTION: An undesired change in output waveform compared with input due to irregularities in amplitude, frequency or phase.

ELECTRO-OPTIC EFFECT: A change in a material's refractive index under the influence of an electric field.

EMISSIVITY: The ratio of power radiated by a substance to the power radiated by a blackbody at the same temperature. Emissivity is a function of wavelength and temperature.

EXTRINSIC JUNCTION LOSS: Those junction losses that are caused by different geometric and optical parameter mismatches when two nonidentical optical waveguides are joined.

FERRULE: A mechanical fixture, generally a rigid tube, used to confine the stripped end of a fiber bundle or a fiber.

FIBER BUFFER: A material that may be used to protect an individual optical fiber waveguide from physical damage, providing mechanical isolation and protection.

FIBER BUNDLE: An assembly of unbuffered optical fibers. A bundle is usually used as a single transmission channel, as opposed to multifiber cables, which contain optically and mechanically isolated fibers, each of which provides a separate channel.

FIBER OPTICS: The branch of optical technology concerned with the transmission of radiant power through fibers made of transparent materials, such as glass, fused silica or plastic. Communications applications of fiber optics employ flexible fibers. Either a single discrete fiber or a nonspatially aligned fiber bundle may be used for each information channel. Such fibers are generally referred to as optical waveguides to differentiate from fibers employed in non-communications applications.

FLUX: Obsolete synonym for radiant power.

FUSER SILICA: Amorphous silicon dioxide.

GAP LOSS: An optical power loss caused by a space between source and optical waveguide, between axially aligned waveguides, or between waveguide and detector.

GEOMETRIC OPTICS: The science that treats the propagation of light as rays. Rays are bent at the interface between two dissimilar media, or may be curved in a medium whose refractive index is a function of position.

GRADED INDEX PROFILE: Any index profile that varies smoothly with radius.

INDEX PROFILE: In optical waveguide, the refractive index as a function of radius.

INJECTION LASER DIODE: A laser employing as the active medium a forward-biased semiconductor diode.

INSERTION LOSS: The total optical power loss in a transmission system caused by the insertion of an optical component such as a connector, splice or coupler.

INTENSITY: The square of the electric field amplitude of a light wave.

INTERFERENCE: In optics, the interaction of two or more beams of coherent or partially coherent light usually derived from a single source.

INTRINSIC JUNCTION LOSS: The total loss resulting from joining two identical optical waveguides.

IRRADIANCE: Radiant power incident per unit area upon a surface expressed in watts per square meter.

LASER: A device that produces optical radiation using a population inversion to provide Light Amplification by Stimulated Emission of Radiation and an optical resonant cavity to provide positive feedback. Laser radiation may be highly coherent, either temporarily or spatially or both.

LASING: The process of emitting laser light.

LAUNCH ANGLE: The angle between the light input propagation vector and the optical axis of an optical fiber or fiber bundle.

LIGHT: In strict sense, the region of the electromagnetic spectrum that can be perceived by human vision, designated the visible spectrum and nominally covering the wavelength range of 0.4 micrometers to 0.7 micrometers. In the laser communications fields, custom and practice have extended usage of the term to include the much broader portion of the electromagnetic spectrum that can be handled by the basic optical techniques used for the visible spectrum.

LIGHT EMITTING DIODE: A junction for semiconductor device that emits incoherent optical radiation when biased in the forward direction.

LINEAR OPTICAL ELEMENT: One in which the radiant power output is proportional to the radiant power input, and no new optical wavelengths or modulation frequencies are generated.

LINE SPECTRUM: An emission or absorption spectrum consisting of one or more narrow spectral lines, as opposed to continuous spectrum.

MODE: In any cavity or transmission line, one of the allowed electromagnetic field distributions. The field pattern of a given mode depends on the wavelength, refractive index, and cavity or waveguide geometry.

MODULATION: A controlled variation with time of any property of wave for the purpose of transferring information.

MONOCHROMATIC: An idealized concept referring to a single frequency or wavelength.

MULTIFIBER CABLE: An optical cable that contains two or more optical waveguides, each of which provides a separate information channel.

OPTICAL DATA BUS: A data bus using optical waveguides and optical waveguide components.

OPTICAL DETECTOR: A transducer that generates an electrical signal that is a function of irradiance.

OPTICAL FIBER: Any filament or fiber, made of dielectric materials, that guides light whether or not it is used to transmit signals.

OPTICAL FILTER: An element that transmits a range of wavelengths and blocks adjacent wavelengths.

OPTICAL LINK: Any optical transmission channel designed to interconnect two end terminals or to be connected in series with other channels.

OPTICAL REPEATER: In an optical waveguide communications system, an optoelectronic device or module that receives an input optical signal, converts it into an electrical signal, amplifies this signal and reconverts it into an optical signal for retransmission.

OPTICAL WAVEGUIDE: Any structure capable of guiding optical power. In optical communications, generally a fiber designed to transmit optics' signals.

OPTOELECTRONIC: Pertaining to a device that responds to optical power, emits or modifies optical radiation, or utilizes optical radiation for its internal operation.

PHOTOCONDUCTIVITY: The conductivity increase exhibited by some nonmetallic materials, resulting from the free carriers generated when photon energy is absorbed in electronic transitions.

PHOTODIODE: A diode having current-vs-voltage characteristics that is dependent on the level of optical power incident on the device. Photodiodes are used for the detection of optical power and for the conversion of optical power to electrical power.

PHYSICAL OPTICS: The branch of optics in which light propagation is treated as a wave phenomenon rather than a ray phenomenon as in geometric optics.

PIN PHOTODIODE: A diode with a large intrinsic region sandwiched between p and n doped semiconducting regions. Photons absorbed in this region create electron-hole pairs that are then separated by an electric field, thus generating an electric current in a load circuit.

PULSE DURATION: The time between a specified reference point on the first transition of a pulse waveform and a similarly specified point on the last transition.

PULSE LENGTH: Often erroneously used as a synonym for pulse duration.

PULSE WIDTH: Often erroneously used as a synonym for pulse duration.

TOTAL INTERNAL REFLECTION: The reflection that occurs when light strikes an interface at incident angles greater than the critical angle.

TRANSDUCER: A device that converts one form of energy into another.

TRANSFER FUNCTION: A complex function equal to the ratio of output to input as a function of modulation frequency.

WAVELENGTH DIVISION MULTIPLEXING: The provision of two or more channels over a common optical waveguide, the channels being differentiated by wavelength.

STATEMENT OF THE PROBLEM

There are very few, if any, programs at a vocational-technical level that address the technology of lasers, fiber optics, or infrared communication and related hardware. To eliminate this deficiency, several levels of approach are needed to develop materials for this advancing technology. Operating and equipment performance requirements for the vocationally oriented student, repair and troubleshooting systems for the technician would begin to address this problem. The materials needed to implement a high technology of this type would include the determination of required learning experiences essential to each level of performance, the selection of equipment that would provide the means for learning the characteristics, application and operation of the hardware and systems involved, and the recommendations for curriculum development that would follow equipment testing, modifications, and application to each level of learning.

PROJECT OBJECTIVES

The following objectives were set forth for this project:

a. To prepare a report describing state-of-the-art developments in fiber optics technology.

b. To review and evaluate applications of fiber optics technology with the intent to provide practical approaches for teaching this technology at the vocational and technical level.

c. To evaluate various fiber optics industries with a view to teach the concepts of this technology at the level of a vocational-technical school.

d. To prepare a curriculum outline reflecting the results of the analysis performed on state-of-the-art automated equipment and including mathematics and other learning experiences to enable and encourage the learning of physics of optics, electronic communications and fundamental semiconductor technology.*

* In the original proposal, this objective was written as three individual objectives. Because of the nature of the format chosen for this final project report, this consolidated objective appeared to be the most practical way both to reflect the initial intent of the proposal and to give the reader a sense of direction and organization.

STRATEGIES TO ELIMINATE SEX BIAS AND SEX ROLE STEREOTYPING:

The school is committed to the avoidance of all sex bias and sex role stereotyping in counseling, recruitment and instruction, as well as the encouragement of both males and females into careers non-traditional to perceived sex roles.

A strong advocacy program exists and has shown success in the recruitment and training of adult women in technical fields. Advocacy for women is promoted at the administrative level by the Affirmative Action Office for the district. At an operational level, counselors and teachers are aware of the need to make special efforts to encourage women to try a non-traditional field of study. Programmatically, the school sponsors electronics education for women. Termed "Women Working Technical," this project was initially funded through Wider Opportunities for Women in Washington, D.C. The Career Development Center for Women provides a full range of services, some of which deal directly with vocational counseling for non-traditional education, apprenticeships, and employment. The Career Development Center has become one of the largest training centers for displaced homemakers in New Jersey and continues to be a strong advocate for technical education and employment for women.

INTRODUCTION

1.1 OPTICAL FIBER TRANSMISSION OVER THE YEARS

Information transmission by optical methods, such as smoke and fire signals, dates back to prehistoric times. However, little advance in these methods appears to have occurred until 1791 when Chappe invented and demonstrated the optical telegraph [63]. This system was widely used in France and in other parts of Europe for more than 60 years. In 1870, the physicist John Tyndall demonstrated that light could be guided along a curved path in water. Subsequently, in 1910, Hondros and Debye [32] laid the foundation for understanding this behaviour when they analyzed dielectric waveguides in their studies of the propagation of radio waves.

In 1880, A.G. Bell invented and patented the " Photophone", which was used to transmit speech signals at distances of a few hundred meters. This system used intensity modulated sunlight reflected from a mirror, atmospheric transmission, and a selenium detector. However, because the system lacked a well controlled medium, a dependable optical source, and a sensitive detector, Bell's Photophone lost out to another, somewhat better known Bell invention - the telephone.

Technical development in the field of optical communications again seemed to cease until the invention and realization of the laser in 1959 and 1960. The prospects of a controlled source capable of transmitting enormous amounts of information, at a time when the importance of information in the society of the future was just being recognized, led to major research efforts to uncover a low loss, well controlled, guided optical medium. The breakthrough occurred in 1966 when Kao and Hockham [38] of Standard Telecommunications Limited proposed a clad glass fiber as a suitable dielectric waveguide. They predicted that a loss of 20 db/km should be attainable in such fibers. These remarkable predictions, at a time when the lowest loss in fibers was about 1000 db/km, led to increasing research in glass materials and processing efforts in many parts of the world. By 1968, bulk silica samples had been prepared with losses as low as 500 db/km [37]. In 1970, Kapron, Keck, and Maurer [39] of Corning Glass Works reported on a doped silica clad fiber that achieved the 20 db/km loss bogey. That same year, just eight years after the development of the first semiconductor injection laser (GaAs, low temperature, pulse operated only), Hayashi and others [31] at AT & T Bell Laboratories achieved continuous, albeit short lived, operation at room temperature and optical confinement, with an AlGaAs double heterostructure device which had a lattice matched to a GaAs substrate.

As promising as these developments were, there still seemed to be enormous obstacles to making optical fiber transmission practical. Some of the major issues at that time were:

1. Could the loss be reduced to the range of a few db/km or less to gain a regenerator spacing advantage over competing wideband technologies, such as COAX ?

2. Could fibers be produced at sufficiently low cost to make optical fiber transmission economically attractive ?

3. Could fibers be drawn with sufficient strength to survive manufacture, cabling, installation, and field use ?

4. Could fiber dimensions and the index of refraction profile be controlled well enough to permit satisfactory transmission characteristics and reasonable splice losses ?

5. Could splicing be performed in the hostile field environment with sufficient alignment accuracy, freedom from contamination, and stability to allow stable system performance?

6. Could practical optical fiber connectors be designed?

7. Could injection laser lifetimes, then measured in minutes, be extended to the tens of thousands of hours needed for real systems?

8. Could laser light be coupled, without large losses, into optical fibers?

In the succeeding 13 years, affirmative answers were reached to these questions, and to other vital ones which had not even been identified. An excellent objective historic account of optical fiber communications was provided recently by li [43].

1.2 LOW LOSS FIBERS - A NEW TECHNOLOGY

Low loss fibers hold the key to the future developments in the field of fiber optics. The lowest loss optical fiber that had been made by 1965 had a loss of about 1000 db/km. As a technically oriented society, we sometimes throw such numbers about with great abandon without giving enough thought to their significance. To put things in the perspective of that time

(1965), let us assume that we wanted to transmit a signal via an optical fiber over a distance of one kilometer(a short distance by telecommunications standards), without amplification or regeneration. Since the weakest signal we can possibly detect corresponds to a single photon, and assuming a source wavelength of one micrometer, the minimal detectable energy is 20x10 joules to get, on the average, one photon out through the optical fiber! One of the many ways to show that this number is absurdly large is to note that the total world energy production in 1981 was 284.51 quadrillion BTU [61]. Hence, it would take 6.67x10 years to produce enough energy, at the 1981 rate,to average one photon out of the one kilometer fiber length(of course the fiber would have disintegrated in the first millisecond!).

In Kao and Hockham's 1966 paper, they concluded: "Theoretical and experimental studies indicate that a fiber of glassy material constructed in a cladded structure represents a practical optical waveguide with important potential as a new form of communications medium. The crucial material problem appears to be one which is difficult but not impossible. Certainly the required loss figure of around 20 db/km is much higher than the lower limit of loss figure imposed by fundamental mechanisms." The Kao-Hockham results stimulated fiber research in many countries. Kapron and Maurer [39] achieved the goal of 20 db/km attenuation in 1970.

Research and development efforts over the last ten years have resulted in the following:

- Dispersion within the fiber core has been reduced drastically.
- Improved dimensional control of the fiber core and cladding has been achieved.
- Signal attenuation has been reduced from several hundred db/km to a few tenths of a db/km.
- Tensile strength has been raised by more than an order of magnitude.
- Connectors and other components have been developed to facilitate installation and interconnection.

All this has been done with an accompanying reduction in cost of the fiber cable from several dollars per kilometer to $0.25 per kilometer.

1.3 FIELD EXPERIMENTS AND FIBER OPTICS SYSTEMS

In order to establish the feasibility and practicality of optical fiber transmission, a number of multimode fiber experiments were conducted in the mid 1970's in Japan, the United States, France, the United Kingdom, Italy and Germany. The first of these, which emphasized cabling and splicing, was carried out by Furukawa during the summer of 1974. It involved 400 metres of 4-fiber cable of which 200 meters was installed in free space; the remaining 200 meters was placed underground. Splicing was performed using a sleeve based technique. Results of the experiment were reported by Murata [36,37]. Optical fiber field trials and early applications in North America, Europe and Japan are described [14,36].

AT&T Bell Laboratories installed an experimental optical fiber trunk system in Atlanta in the latter part of 1975 [40]. The system used a 650 meters, 144 fiber cable that was configured in a loop which passed through underground ducts. Hence, optical signals could be sent through the cable many times to establish long transmission lengths by appropriately connecting different fibers of the cable with short jumpers at two single fiber jack fields. The cable of the ribbon type was mass spliced using 144 fiber array connectors [50], with an average loss of .8 db. A full range of system experiments was carried out at 44.7 Mb/s, which yielded unrepeated splicings at distances up to 10.9km having error rates of less than 10 and negligible crosstalk even with mass splicing.

The most significant aspect of the Atlanta experiment was that it established the viability and practicality of all aspects of optical fiber trunk transmission, including the optical cable medium, its installation, splicing, optical transmitters and receivers, electronics, optical jack fields and jumpers, and optical system performance. The success of the experiment led to the decision to install a similar system in underground ducts in the Chicago "loop" area. The system which began carrying service in the spring of 1977, provided digital video transmission for use with experimental 45 Mb/s video terminals along with data and voice. The results of this effort led to the FT3 45Mb/s lightwave trunk development, which began in 1978 and to the first standard service in September 1980 in the Atlanta-Smyrna area. Miller [50] reported that as of December

1984, more than 300,000 km of cabled optical fibers had been installed in what was the Bell system [43] for these same systems and for fiber loop carrier applications [8].

The first major field test using optical fibers to bring broadband services to individual residences was the Hi-OVIS project [45] in Japan, which began in 1978. It used LED's and plastic clad step index glass core fibers and baseband transmission to provide a very broad range of video services, including two way video using channel selection signals. It involved 168 subscribers and was configured to help meet the social requirements and community needs set by the Ministry of International Trade and Industry (MITI).

At this time, optical fiber systems became more than an "interesting new technology." In many places and instances around the world it has now become necessary to justify when anything other than an optical fiber system is proposed for trunk or long-haul right of way applications. This is the case in a number of Bell Operating Companies, in the United Kingdom and Canada, to name a few. Major long haul routes in the United States include a 776-mile FT3C route along the East coast from Mosley, Virginia to Cambridge, Massachusetts and a 500-mile FT3C system in California linking Los Angeles and San Fransisco.

Single mode fiber systems, with their inherently larger bandwidth and longer repeater spacing capability, are the main thrust in new systems for long and short haul applications. Nippon Telegraph and Telephone (NTT) in Japan has sponsored a field trial of a 400 Mb/s SM fiber system between Musashino and

Atsugi, an 80 km route passing through 11 cities with 4 intermediate repeaters [40]. The system operates at 1.3 micrometers and uses a cable with 6 single mode (SM) fibers, 6 graded index multimode fibers (for comparision purposes), 2 power feeders, and 6 quads. The NTT trial was due to be completed in December 1985, and is to be introduced into the long haul network in 1986. Announced plans indicated more than 60 such installations and 90,000 fiber kilometers beginning in 1987.

In addition, both United States and the United Kingdom have announced plans for major long haul routes using SM fiber [46-47]. some short haul systems are already in operation [64]. Undersea lightwave systems are being aggressively pursued in the United States, the United Kingdom, France and Japan. A Deep Water Sea Trial of an undersea lightwave system was carried on by AT&T Bell Laboratories in September, 1982, at a depth of 5.5km [49,50]. The results of the trial include the following :

1. The 18.2km cable, which contained 12 low loss high strength fibers, performed as anticipated during laying, holding, and recovery operations.

2. Error free transmission at 274 Mb/s was demonstrated at 1.3 micrometers in a concatenation of 3 regenerator spans(a length of 109 fiber km). The signal was looped through the cable three times (54.6 km) to one underwater regenerator, then looped two more times to a second underwater regenerator(36.4 km), from which it passed through the cable one more time (18.2 km) to a shipboard regenerator.

3. The maximum change in loss due to temperature, tension, and pressure was less than .1 db under all conditions.

In November, 1983, it was announced that AT&T had been awarded a major portion of the first transatlantic lightwave cable system, known as TAT-8 [3]. The Deep Water Sea Trial previously

referred to laid the groundwork for, and established the viability of, the technology AT&T will employ. AT&T will provide the segment of the system from a landing point in Tuckerton, New Jersey to a branching device off the European continental shelf. AT&T will supply 3146 nautical miles of undersea cable, repeaters and terminal equipment. Standard Telephone and Cables will supply 279 nautical miles of cable, as well as repeaters and terminal equipment to reach Wildermouth, England from the branching point; Submarcom will do the same for the 167-mile link from the branch point to Fenmarch, France. AT&T Communications was given the responsibility for ensuring the technical compatibility of the three parts of the TAT-8 system. The system, which is planned for service in June 1988, is expected to provide the equivalent of 40,000 two way telephone channels.

As a measure of progress in the experimental systems area, the "world record for the longest unrepeated transmission distance" in a laboratory demonstration changed hands three times last year. Early in 1983 a world record of 119 km was achieved at AT&T Bell Laboratories at a 420-Mb/s rate [67]. In June 1983, Nippon Telegraph and Telephone succeeded in reaching 134 km at 446 Mb/s [54]. In the spirit of "can you top this," AT&T Bell Laboratories reached 161 km spacing at 420 Mb/s [54]. These incredible spacings at such high bit rates are not practical today for real systems because such laboratory systems do not account for system margins, reliability, physical constraints on splices, and above all, costs. However, they do signify the tremendous rate of progress being made, and it is possible that

in a five to ten year period these parameters will be achieved in commercial systems.

1.4 OUTLOOK FOR THE FUTURE:

Currently, fiber research efforts are moving to the longer wavelength range beyond 2 micrometers, where Rayleigh scattering losses can be much lower. Unfortunately, this means abandoning the high silica glasses because of their infrared absorption. A number of material systems including germanium, fluoride, and chalcogenide glasses are under investigation[55]. Thus far, fiber losses have been high primarily due to impurities. Although some of these systems have the potential for losses below .01 db/km, it will take considerable effort to get down to the .16 db/km minimum reported for high silica fibers[56]. Even if the impurity problems are solved, there are significant physical property issues and difficult cost problems to be solved before longer wavelength systems become practical. Nevertheless, the payoff potential is so large that it is "well worth the hunt."

Other areas which appear to have significant potential, particularly for long wavelengths, are coherent transmission and detection. Coherent systems have the potential of achieving the quantum noise sensitivity limit; however, they require single frequency stabilized transmitters and local oscillators. Depending on the system parameters and choices, such as bit rate and type of detector, improvements in system sensitivity of the order of 20 db are theoretically possible. Recently, two

techniques have been reported for injection locking a diode laser and attaining full width and half maximum line widths of less than 10 khz [65]. Using an injection locked transmitter and an HeNe local oscillator to perform heterodyne detection, a sensitivity improvement of 14 db at 8 mb/s was measured over 123 km of fiber relative to a pin photodiode. Many issues remain to be resolved, such as laser stability, polarization preservation in fibers, and nonlinear propagation effects, but there is reason to be optimistic.

Much progress has also been made in sources and detectors. These developments will further enhance the ability of the new optical fiber technology to do old transmission jobs better and more cheaply than other guided transmission systems. Perhaps this will eventually lead to the same kind of qualitative effect that integrated circuits have had on electronic systems, that is, allowing society to do things that were inconceivable before the transistor and its long line of descendant developments. But, for a while at least, we will focus on the quantitative side, emphasizing higher speeds, longer distances, and lower costs.

STATE OF THE ART

2.1 FIBER OPTICS RESEARCH AND DEVELOPMENT - A GLOBAL REVIEW

Emerging fiber optics technology, already making inroads in the commercial telecommunications field, promises to deliver multiple benefits in a wide variety of systems engineered to meet the exacting requirements of aerospace/military applications. Some of the promise is already being realized in improved command, control and communications systems--a prime development area moving quickly toward field implementation. Somewhat further on the time scale are significant applications in guidance and control systems for aircraft, spacecraft and missiles, optically multiplexed data transmission systems, electronic warfare and sonar applications and advanced instrumentation systems.

Among trends in technology, the movement toward longer wavelengths is expected to further reduce attenuation over long fiber links. Several promising techniques for optical wavelength division multiplexing also are emerging in the laboratory work. Application of optical multiplexing would afford increased simplicity and reliability, eliminating the need for current electronic multiplexing equipment. Applications leading towards a fault tolerant computer system are being examined by the engineers of the National Aeronautics and Space Administration (NASA), along with systems designed to distribute time and

frequency signals more effectively over extended distances. Other major NASA work is pursuing advanced guidance and control systems and multiplex data bus systems.

Hughes Aircraft, with International Telegraph and Telephone's Electro-optics Products Division, is developing for the Army a two way fiber optics communications link that could be the basis for low cost "lock-on after launch" tactical missile systems.

In the Naval area, a versatile family of sensors employing optical fibers is being developed by the Naval Research Laboratory and its contractors, providing detection and measurements of a variety of phenomena, including acoustics, magnetic fields, temperature and pressure sensing, angular velocity measurements and acceleration.

Major focus of the Navy's fiber optics sensor system program is on acoustic sensors for sonar/antisubmarine warfare applications. In England, Marconi Avionics is continuing its work on fiber optics "fly by light" systems. Possible application is anticipated on an advanced supersonic vertical takeoff and landing (STOL) aircraft.

On the European continent, emphasis on commercial telecommunications applications is slowly giving way to some aerospace applications, such as an experimental fiber optics bus system tested on the Dassault Breguet Mirage 4000 aircraft. Although a significant proportion of the optical fibers produced in Germany are dedicated to telecommunications applications, research and development programs in the defense area are growing. Engineers at Messerschmitt Boelkow Blohm (MBB), Germany, are

pursuing fiber optics developments in avionics and aircraft systems, with most efforts geared to the needs of a future combat fighter of the 1990's. MBB's approach is to develop systems, leaving required equipment and technology developments to the fiber manufacturers.

Italian industry is looking at a number of applications, including satellite on board systems, radar subsystems, weapons, communications, electronic warfare and ship integrated data distribution systems. An experimental system for an Italian navy ship was developed by the Central Laboratory of Industrie FACE Standard installed on the destroyer Ardito for a practical demonstration.

A group of engineers at Selenia has studied applications of the fiber optics technology to satellites, particularly for on board signal routing to eliminate mass and electro magnetic susceptibility (EMI), and for information demodulation and processing.

Japan's National Aerospace Laboratory is working on possible applications of fiber optics technology tc signal circuits on board a STOL research aircraft now under construction, encompassing sensors, actuators, instruments, internal communications and controls. The C-1 modified research vechicle, being built by Kawasaki is expected to fly in December 1985. Fiber optics have also been used in a flight simulator for the aircraft, using a device designed and built by Fujistu Ltd. The laboratory has continued fly by light studies utilizing a system delivered by Nihon Electric Co., Japan.

2.2 EMERGENCE OF A NEW CLASS OF OPTICAL FIBERS:

The accelerating technology revolution is likely to gain added impetus as promising new classes of optical fibers and advances in multiplexing technology emerge from the laboratory. In-house research and development programs are directed toward improved utilization of fiber optics technology, with implementation of wavelength division multiplexing, an extension of frequency division multiplexing techniques to optical frequencies, in which each individual optical channel is transmitted on a distinct wavelength, and with continuing development of new "super long wave" fibers. Future expansion is seen in application of longer wavelength systems, specifically cables that permit transmission at both 0.8 - 0.9 micrometer wavelengths using mature gallium aluminium arsenide source and silicon detector technology and simultaneously at the 1.3 micrometer wavelength, using technology now emerging from the laboratory. Systems operating at the 1.3 micrometer wavelength reduce attenuation from about 3 to 5 db/cm, typical at 0.8 micrometer wavelength, to about 0.5 to 1.5 db/km according to Mitre Corporporation Bedford,Massachusetts. The longer wavelength would employ indium gallium arsenide phosphorous. This technology reflects on the improved transmission distance. Transmission distance approximately triples. A system replacing silica glass fibers with fluorozirconates would operate in the near to mid infrared region of the spectrum, employing lead selenium telluride sources and mercury cadmium telluride

detectors, taking advantage of the considerable developments in this field that have come from military infrared technology for night vision and reconnaissance applications.

There is, however, a strong incentive in the military services to develop nuclear inert fibers. Fluorides are now where silica was in the early 1970's, but technology development results may be expected to benefit from experience with silica fibers. Between 1968 and 1976, attenuations of 1000 db/km in silica declined to about 1.6 db, and we expect to see intense development efforts in fluorozirconates. Mitre scientists are also pursuing wavelength division multiplex technology and efforts are in progress at both Electronic Systems Divivision and Rome Air Development Center.

System reliability would gain tremendously from a wholly passive wavelength multiplexing and translating the main carrier to light transmission technology, according to Bruce Metcalf of the Mitre staff. Aluminium dopant in the gallium aluminium arsenide sources for the short wavelength varies the wavelength, but a selective process is required to provide diode detectors. In his laboratory work, Metcalf is looking at use of a Selfoc microlens, made at Japan's Nippon Sheet Glass Co., to both collimate and focus light in conjunction with a reflective diffraction grating that reflects light at various wavelengths to the respective diodes for each channel, employing wavelength as a function of position.

The 1,600 line grating that Metcalf is using has produced five multiplex channels. A positioner holds the individual fibers

in accurate alignment, and their assembly is potted in an epoxy compound. Using this configuration, which was originated by W. J. Tomlinson at Bell Laboratories in 1977, Metcalf has measured optical insertion losses averaging 2.5 to 3.5 db, with optical crosstalk at about 30 db. Optical filters might further reduce this significantly.

In his research and development program Metcalf is concerned with getting the light sources at the exact wavelengths he wants. Efforts by manufacturers to standardize their sources make this effort more difficult. Mitre scientists, however, believe that two to three channel systems could be implemented within the next few years, although multichannel wavelength multiplex systems are farther in the future. They are convinced that wavelength multiplexing can increase the information carrying capabilities of fibers and that their use as an alternative to conventional multiplexing techniques can improve reliability and size of terminal equipment. One concept implemented by Mitre's Kenneth Taylor could overlay wavelength division multiplexing onto existing systems to provide increased channel capabilities. Efforts are underway to develop a single fiber bidirectional capability, permitting operation of the single fiber link in a full duplex mode. While point-to-point fiber optics systems are regarded as a maturing technology, fiber optics bus or distributed architecture systems are more of an emerging technology that promises to be important in the future.

2.3 N A S A 's FIBER OPTICS RESEARCH PROGRAMS:

The National Aeronautics and Space Administration is engaged in a variety of fiber optics programs aimed at aircraft, spacecraft and ground system applications that could profit from the high data handling capabilities and immunity to electromagnetic and radio frequency interference inherent in the optical medium.

Opportunities for higher levels of safety, system stability and accuracy of control are other benefits that are encouraging NASA projects in this area. In many application areas, the weight and volume savings that fiber optics offers in comparision with electrical/electronic implementation of the same functions furnish additional incentives.

Fiber optics projects are widely distributed throughout the NASA centers and at the California Institute of Technology Jet Propulsion Laboratory (JPL). A fiber optics multiplexing scheme for possible use in fault tolerant computer systems for civil aviation is being explored at Langley Research Center, and multi-wavelength monolithic fiber optics terminal development for spacecraft applications is being sponsored by Johnson Space Center.

Johnson Space Center is also investigating the use of fiber optics to distribute extremely precise and stable reference signals in large phased array antennas and other structures in space, and the use of fiber optics sensors in cryogenic environments.

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JPL is studying the use of fiber optics transmission lines for distributing stable time and frequency signals over extended distances at Deep Space Network facilities. Spacecraft buses, picosecond pulse generation for multi-gigabit digital transmission systems, and fiber optics gyros for high accuracy spacecraft guidance and control applications also are under study at JPL.

Other NASA programs center on the development of a 32-port databus for scientific satellites by Goddard Space Flight Center and possible use of fiber optics communication and data transfer links on a science and applications space platform being defined by Marshall Space Flight Center.

Langley's wavelength multiplexing project is related to the center's controls and guidance program and energy efficient transport program. Advanced control techniques, including maneuver load control and other active control concepts, can make aircraft more efficient and profitable to operate, but these concepts will not be accepted unless the failure probability in the on board data distribution and processing equipment is less than one in a billion per hour of flight.

The fiber optics wavelength division multiplexing scheme that Langley is investigating as an interconnection between sensors, computers and actuators is expected to meet this stringent reliability criterion and to overcome several of the problems associated with wire connected systems.

Redundant wire buses utilizing time division multiplexing offer a straightforward solution to the data distribution

requirement of high reliability control systems, but are subject to monopolization of a bus by a "babbling" transmitter--one that transmits continuously onto the bus as a result of a malfunction.

An alternative wired interconnect that is designed to circumvent such a problem is the reconfigurable network bus that can locate, isolate and bypass a malfunction within a system. Each aircraft subsystem would be equipped with an optical transmitter that operates at a wavelength which is unique within the system.

The various transmitter wavelengths would be mixed in the multiplexer and the combined signals would be transmitted by fiber between the multiplexer and each subsystem. A demultiplexer at each aircraft subsystem would separate the wavelengths and appropriate detectors would convert each optical signal into an equivalent electrical signal. This type of system does not need a control protocol to sequence transmissions as a time division multiplexed system does. Furthermore, a subsystem that babbles affects only its unique wavelength.

Langley has constructed an experimental system employing four transmitters, a four input/four output multiplexer and four multiplexer receiver units. The four aluminum gallium arsenide transmitters emit at 790, 810, 830 and 850 nanometers respectively. The multiplexer utilizes the bi-conical taper coupler concept, and two types of interfernce filter demultiplexers-assembled from discrete optical components have been built to date. The detectors are silicon PIN diodes.

Langley awarded a contract last spring to Hughes Aircraft Co. for an advanced demultiplexer that it will use in the second phase of its investigation. The Phase 2 device, which is expected to be delivered in April or May, 1986, is a passive laminated waveguide device with a surface area measuring approximately 1.5x1.3 in. The input fiber and four output fibers will be located at precise points along the device's curved front face and a diffraction grating will be situated along its curved rear face. The grating separates the combined input into its individual component wavelengths and focuses these onto the appropriate output fiber.

NASA is looking for 50 Angstrom separation between channels with better than 30 db cross talk isolation, according to Huan-Wun Yen, a member of the technical staff at Hughes Research Laboratories in Malibu, California where the device is being developed. Hughes has demonstrated devices that can provide better than 20 db isolation between adjacent channels that are separated by 200 Angstroms.

Hybrid assembly techniques should enable the integration of additional functions on the demultiplexer assembley, Langley researcher Herbert D. Hendricks said. The center plans to replace the output fibers with a photodiode array. A technical report that Hendricks coauthored with Langley's J. Larry Spencer and Carl J. Magee portrayed a hybrid concept that included the diode array, detector preamplifiers and amplifier chips assembled on the basic waveguide device.

A comparable space-oriented effort is under way at Johnson Space Center. Johnson regards fiber optics as a likely candidate for space vehicle data buses because of their potential for handling high data rates unaffected by electromagnetic or radio frequency interference and with low power, weight and volume budgets as compared with wire buses.

A key element of Johnson's program is the multiwavelength monolithic fiber optic terminal that McDonnel Douglas Astronautics Co. is developing for the Center. The terminal, which is intended for fabrication as either a transmitter/ multiplexer or demultiplexer/receiver is designed to handle eight independently modulated light frequencies.

The integrated optics terminal will include a deposited slab wageguide, lenses, chirped (non periodic) grating and coupling to a single mode fiber. The transmitter module will have eight injection laser diodes and the necessary interface to the associated electronic channels, and the receiver module, a PIN diode array and array electronics. The terminal is designed for fabrication on a 2x2 in. silicon substrate.

McDonnell Douglas recently completed a demonstration test intended to show that an integrated optical demultiplexer would demultiplex data transmitted by a single mode optical fiber. During the test, recorded video and audio analog data were converted into 6 bit digital data that was used to modulate aluminium gallium arsenide laser diodes at a rate of 80 megabits per second. The laser diode wavelengths were separated by 8 nanometers.

The laser outputs were combined by a prism and transmitted through a single mode fiber and the fiber output beam was directed into the polished edge of a one micrometer thick sputtered glass waveguide on a two inch diameter silicon wafer. A tantalum pentoxide Luneberg lens was used to collimate the guided wave before it was directed to the chirped diffraction grating. The grating separated the combined wavelengths, which were focused by thin film step index lenses, and a prism coupled out of the optical waveguide and directed to separate detectors. The outputs from these detectors were converted back into audio and video data and fed to a color television monitor.

The TV monitor image quality of the digitalized and multiplexed-demultiplexed data was not visibly reduced in comparison with a direct playback of the recorded video data, Johnson Center engineer W.R.Reed said.

As part of its solar power satellite studies, Johnson Space Center investigated the use of fiber optics to distribute critical phase information throughout the large space antenna that such a satellite would employ to beam energy down to Earth. A large phased array of this sort would require extremely stable phase information to maintain its RF beam quality.

The Center had Boeing Aerospace Co. investigate and test several types of fibers to determine the effect of temperature changes on phase stability. Boeing also built and delivered to Johnson an experimental one km fiber optic link with breadboard transmitter and receiver designed to operate at 980 GHZ. This hardware is being modified for studies of potential fiber optics

applications in a Space Operations Center (SOC). Weight and space savings, interference free operation and high data rate capabilities, all could be important benefits in this environment. Bandwidths in SOC data transfer links could be extended into the gigahertz range, according to one Johnson source.

Liquid Level Sensors :

Boeing developed a fiber optics liquid level sensor and built an experimental model that was tested with liquid nitrogen. The company also did some work with fiber optics temperature and pressure sensors and generated some ideas for a fiber optics leak detector and liquid quantity measurements in a zero gravity environment.

Optical fiber systems are being developed at JPL to distribute ultrastable frequency reference signals over distances up to 30 kilometres. The reference signals, generated by standards such as hydrogen masers are to be distributed between Deep Space Stations within each of NASA's Deep Space Communications complexes.

Although their use is still in the development stage, optical fibers appear to be the most suitable medium for distributing these signals because of their inherent stability, immunity to interference, wide bandwidth and low loss. Using this technology it should be feasible to distribute reference signals from a

single, centrally located frequency standard to all of the stations in a Deep Space Communications Complex (DSCC). This will eliminate the need to have a complex and costly frequency standard and possibly a backup at each station.

Once you tie a DSCC together in frequency and time, it would be nice if you could have a central processing area where you can take all of the intermediate frequency data from each of the (receiver) front ends instead of processing the data at each individual station in the complex. That represents a considerable saving because you need only one computer, with maybe one backup, instead of two computers at each station.

The intermediate frequencies coming out of the antenna front ends are as wide as 400 MHZ and JPL would like to be able to send those signals as far as 20 km. without seriously degrading the phase relationships. Using the outputs of multiple stations in this way (DSCC's have up to five stations) provides higher quality signals and allows operations at higher data rates than would be feasible otherwise, according to Richard M. Dickinson of JPL's Telecommunications Science and Engineering Division.

JPL has built a 3-km experimental link for evaluating the use of fiber optics frequency reference distribution systems and the laboratory has achieved a stability of 4 parts in 10 for an averaging time of 100 sec. with a multimode fiber system operating at an 850 nanometer wavelength. The stability was limited by the optical transmitters and receivers, which are being improved.

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Data and Control Signals:

A fiber optics cable was used to carry data and control signals between the transmitter located on the movable portion of the antenna and the control station located on the ground. In this application the choice was governed by the space savings afforded by the fiber optics cable. There simply was insufficient room to accommodate additional wire cables in the cable wrap up between the two points.

JPL is developing a single frequency Sagnac interferometer gyro to investigate the possible use of such devices in spacecraft guidance and control applications.

Conventional gyros have been used as backup in spacecraft altitude control systems and during fly by periods and other critical phases of planetary missions. But their limited life and limited longterm stability have precluded the laboratory's use of spinning mass gyros for continuous duty in spacecraft. The laboratory became interested in fiber optics for spacecraft guidance and control applications about three or four years ago, when it suddenly became clear that people would be able to make (optical) waveguides with such low losses that it would be possible to build multi-kilometer lengths and still get a reasonable signal through it.

The experimental interferometer that the laboratory is developing uses a pulsed gallium arsenide laser diode, a fixed phase bias, dual silicon photovoltaic detectors, a 2-km fiber coil and a double pole double throw optical waveguide switch that modulates the Sagnac phaseshift by periodic reversal of the

connections to the sensing coil. A 16-bit microprocessor controls the gyro, using a separate arithmetic chip to perform trigonometric function calculations.

2.4 FIBER OPTICS RESEARCH AT NAVAL RESEARCH LAB, WASHINGTON:

Versatile family of sensors, using optical fibers capable of detecting and measuring a variety of phenomena including acoustics, magnetic fields, temperature, pressure, angular velocity and acceleration, is being developed here by the Naval Research Laboratory and its contractors.

The focus of the Fiber Optic Sensor System (FOSS) program is on acoustic sensors for sonar/antisubmarine warfare applications, according to John E. Donovan, FOSS Program Manager. The effort is sponsored by the Navy and Defense Advanced Research Projects Agency.

Experimental optical fiber acoustic sensors already are an order of magnitude better than the best of the conventional acoustic sensors in terms of threshold detectability. Optical fiber magnetic field sensors capable of detecting fields as small as 10 to 10 appear feasible. This rivals the best contemporary magnetometers which are more complex and costly. The new type of acoustic sensor also would use optical fibers in their more traditional signal interconnection role, and this should result in sonar towed arrays that are far less bulky and less expensive than current designs. This, in turn, would permit their use on smaller vessels, such as submarines, that today cannot carry conventional towed arrays.

Single mode fiber:

The more advanced and far more sensitive approach is to use a very small diameter optical fiber that will propagate only a single wavelength of light. This concept has been successfully implemented at Naval Research Laboratory's Acoustics Research Division. When such a single mode fiber is coupled to the phenomenon to be measured, variations in the phenomenon produce changes in fiber length or refractive index that result in changes in the phase of light passing through the fiber. These phase changes can be measured using optical interferometric techniques that convert the phase change into a more convenient amplitude modulation of an output signal.

The challenge is to produce reliable fibers whose diameter necessarily must be extremely small to assure single mode propagation. The technology for making single mode fibers only recently has emerged from the research stage. Japanese suppliers rather than U.S. companies are moving most rapidly to exploit the new technology. One reason for this is that multimode fibers are adequate for most transmission link type applications which currently offer a much larger market.

When optical fibers are employed for more traditional applications, to replace coaxial cable, for example, amplitude modulation of the signal due to external environmental factors is undesirable, prompting efforts to isolate the fiber from such

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effects. The idea of exploiting this normally unwanted characteristic to develop sensors to measure such effects originated in the Naval Research Laboratory nearly five years ago.

By this time the Navy was investigating the use of optical fibers as a transmission link between a conventional towed array and its vessel, as a promising means of returning wideband sensor data. If both sensor and transmission link used optical fibers, this would minimize signal conversion and interface problems.

In a typical single mode optical fiber type of sensor, the output from a coherent light source, such as diode laser, travels down two different fibers, one of which is exposed to the phenomenon to be measured while the other intentionally is isolated from it. Then the phase of the exposed and the isolated light is compared by means of an interferometer which converts the phase difference into an output signal amplitude.

Another facet of the FOSS program is focused on the development of inertial sensors to measure acceleration and angular velocity for use on low cost tactical missiles. To measure acceleration, a mass is suspended from a single mode optical fiber fed by a diode laser. Any change in acceleration along the sensitive axis stretches the fiber and produces a change of phase that is detected and converted to an amplitude modulated output. The sensor operates in the traditional force rebalance mode to relieve tension on the fiber. Experimental models in the laboratory have proved to be very sensitive, with frequency response extending to several hundred Hertz.

The angular velocity sensor resembles the ring laser gyro except that the contra-rotating laser beams travel through a multiloop coil of optical fibers rather than a single loop optical cavity. The principle is based on what is known as the Sagnac Effect. Rotation of the sensor creates a change in phase between the two contrarotating beams.

A number of companies active in the conventional gyro and the inertial sensor business have expressed interest in optical fiber gyros. But the Naval Research Laboratory has not yet funded any of these companies because they lack the requisite experience in basic optical fiber technology. The NRL is seeking ways to reduce the susceptibility of optical fibers to damage from nuclear radiation as well as to develop optical fibers that can operate at temperatures of up to 800 degrees Centigrade, to permit their use in close proximity to aircraft engines.

Still another goal is to develop very high strength fibers that can be attached to and payed out from torpedoes or tactical missiles. In these applications, the optical fiber is used both to transmit guidance to the weapon and to transmit back imagery information from a television camera or other imaging device in the nose of the weapon.

Optelecom Inc., in the suburban Washington, D.C. area, is pursuing this type of application, especially for tactical missiles. In hilly terrains, an optical fiber transmission link enables a human operator to see targets not otherwise visible and to direct the weapon at the targets. Optelecom is under contract to the Army Missile Command for such an application as a result

of expertise it developed in paying out optical fibers for a high speed missile over considerable distances.

Hughes Aircraft Co. is developing a two-way fiber optics communications link that could be the basis for "lock-on after launch" tactical missile systems, under a contract from the Army Communications & Electronics Command. ITT Electro-Optical Products is supplying fiber optic cable and other components under a subcontract.

The Naval Research Laboratory also is working in the more traditional data transmission applications, seeking to exploit the new single mode fiber technology which permits much greater bandwidths. The current effort is focusing on developing extremely high speed electro-optical switches to permit interconnection between different data loops.

2.5 FIBER OPTICS RESEARCH ABROAD

2.5.1 FRENCH GEARING FIBER OPTICS RESEARCH TO AEROSPACE APPLICATIONS

France is beginning to expand its application of fiber optics to aerospace related applications, but general use of this technology in the demanding aircraft and space environment still is maturing.

Fiber optics are starting to find their way from France's well developed telecommunications industry into such applications as satellite and aircraft-based systems, but a broad push into

aerospace applications is only now beginning to appear. The French industry is looking at fiber optics for military applications, particularly for its nuclear and electromagnetic pulse (EMP) hardening characteristics, but potential for weight savings and operational improvements also is attractive for system designers.

Several French industry researchers said fiber optics components often were too fragile, bulky and complex to have found widespread aerospace acceptance in the past, but they said these drawbacks are being overcome. Additional technology refinements will have to follow recent fiber optics advances before a broad base of usage is achieved in military and civilian aerospace systems, according to these researchers.

"We are passing beyond the more classical applications of fiber optics, such as instrument panel lighting and for basic indicator systems, and are making progress toward more advanced utilizations," an industry avionics manager said. "When it comes to optical data buses, we are beginning to see the refinement of technology as well as the improvement of productivity for such systems. But we still have a long way to go before we see the routine use of fiber optics in the aerospace field on a large scale."

Thomson-CSF is one of the most active French companies in aerospace fiber optics, and it has established a broad design, development and production capability through its various divisions. One of Thomson's current points of focus is optical data transmission systems for both point-to-point and data bus

applications. These are expected to have various military uses, starting initially with shipboard installations, and followed by airborne uses.

With internal funding and contractual agreements with French military organizations, Thomson is evaluating several optical bus arrangements that could have a range of uses. One is point-to-point fiber optics data system equipped with light emitting diodes (LED's) as the optical emitter and PIN diodes in the optical receiver. The incorporation of LEDs normally is restricted in fiber optics systems because of their lower output levels, but this is not a limiting factor in aircraft uses, where system lengths generally are 200 meters or less.

As for the optical receiver element of the optical bus, Thomson-CSF is studying the use of PIN diodes with a sensitivity of about 45 db/m at 100 microwatts in a high data rate environment.

The company's microwave component division has received a French military administration contract to develop military qualified fiber optics components--particularly LED and PIN devices. A Thomson-CSF division is looking at fiber optics connectors that will meet these French military standards. This research is being done with internal company funding and is aimed at producing lower cost, high capability units.

Thomson-CSF's LTT and Cabeltel divisions are studying optical cables that could find a range of military system uses. The company has been working on two specific kinds of cables that have the potential for aerospace applications: one would carry

up to six fibers in a cable composed of dielectric material with metallic strength members and the other would be a special plastic strengthener. The company is carrying out a study under government contract to overcome operational problems at the 55° C temperature range, and progress has been made in achieving satisfactory operation in this region. For nuclear hardening considerations, Thomson-CSF is replacing the steel strengthening members with a special plastic strengthener.

A more advanced cable is under developement by the LTT Division, which utilizes a V grooved, star shaped element running inside the cable. Ten fibers can be carried in a 4.5 mm. dia. cable with better performance than classical cables carrying two fibers. The fibers in the grooves have less contact with the cable than in other cable designs.

In the field of optical data buses, Thomson is extending a new concept utilizing a star coupler system for the grouping of as many as 20 channels in a single coupler unit. Star couplers were studied through a contract from the French Government's military electronics organization. Two types of star couplers were evaluated: one with up to 20 fibers feeding to connectors in a glass base where reflection is provided by a metallic surface on the bottom, and the other with a similar number of connectors fitted on each side of the connector and linked by a single tube. Star coupler production now has started in Thomson-CSF's Socatex division following an extensive study phase.

Thomson-CSF also is studying a diode called EROS (emitter-receiver for optical systems), which can be used as the emitter

and the receiver. This would eliminate the need for separate emitter and receiver units.

Another French fiber optics work, Electronique Marcel Dassault (EMD), has conducted airborne evaluations of two optical bus systems in the Marcel Dassault Breguet Aviation Mirage 4000 fighter aircraft prototype. Optical bus equipment was installed on the Mirage 4000 beginning in June 1980. The work was funded by EMD and the participating French connector manufacturers Compagnie Deutsch and Souriau.

The bus systems linked avionics in a bay behind a pilot with other equipment situated forward of the cockpit, and data from the bus was tied into a terminal connected to the instrument panel-mounted Machmeter. The bus also included coupler units that simulated installation of other terminals to study system losses when other equipment is tied to the bus. Conclusions of the evaluations were that significant progress still is required before such buses can become operational in the military environment, particularly in the temperature ranges of the fighter flight envelope. The use of such optical bus systems also requires special attention in grouping maintenance situations where normal handling could cause damage to the systems. The evaluation also pointed up the problems encountered in pollution of connectors from dirt and through basic handling by ground personnel. It underscored the need to provide protection for the system during regular ground handling and aircraft maintenance. At one point in the Mirage 4000 evaluation, a metal cover was installed above couplers in the rear equipment bay to

protect them from damage.

2.5.2 GERMANY'S INVOLVEMENT IN INTENSIVE RESEARCH

Potential market expansion in the fiber optics field in the next ten years is stimulating massive basic and applied research by West German electronics and communications companies, with about 10% of the future market linked to defense, avionics and other non-communications industry related uses, according to Werner Brendel, Director of the Cable Division of Standard Elektrik Lorenz (SEL).

Brendel said that while growth in the German fiber optics market is largely linked to future mass communications systems, optical fiber manufacturers are also pursuing other potential fields through research and development programs that are broadening the nunmber of applications for the fibers.

SEL first involved company divisions in the fiber optics field about six years ago when it formed a small group of engineers to begin research. Although some fiber optics technology was transferred from other companies within the International Telephone and Telegraph (ITT) group, which includes SEL, Brendel said most of the research and development was carried out entirely by SEL divisions in Germany.

SEL has been active in optical fiber communication and development of all associated components, including lasers, fibers, couplers, photo detectors and systems electronics. The company's research and development program recently achieved three significant developments in the field of digital optical

fiber communication:

1. Unrepeated transmission of a data stream of 1 gigabits/sec. over 25.3 km. single mode glass fiber using a semiconductor laser operating at a wavelength of 1.3 micrometers.

2. Coupling of light from a laser into a single mode fiber employing a new coupling array developed by the SEL research laboratory, with a loss of 1.5 decibels.

3. Single mode glass fiber link of 25.3 km. length with 0.76 db/km mean attenuation including splice joints operating at a 1.3 micrometer wavelength.

A new communication system was displayed earlier this year at the Hanover Fair. The wideband communication system demonstrated to the public operates with two Japanese diodes, including a buried heterostructure laser and a germanium avalanche photodiode. The fiber which is manufactured by the British ITT associate, Standard Telecommunications Laboratories (STL), has a core diameter of 7 micrometers and an outside diameter of 125 micrometers.

The link is made up of fiber lengths of 5 km. No connectors are used in the experimental system, which was demonstrated in operation at the fair. Since the cables are immune to electromagnetic interference, they require no protective measures when laid along high voltage lines in the vicinity of transformer stations or along electrified rail routes. Since atmospheric discharges also do not have any effect on them, no lightning protection is needed.

Until recently, work on optical fiber communications systems at SEL concentrated on spectral ranges around 0.85 micrometers because optical transmitters using gallium aluminium

arsenide devices and silicon avalanche photodiode receivers were available for this wavelength.

SEL developed a laboratory model that allows unrepeated transmission at 34 megabits over a distance of atleast 30 km. The research work was supported by the West German Ministry of Research and Technology. This system was demonstrated to the project sponsors.

In the area of mobile military applications, the SEL Cable Division has developed a fiber field cable that incorporates two plastic-covered glass fibers serving as light conductors and a dummy element filling out the remaining circular cross-section. The most outstanding feature of the optical transmission system is that it does not need optical contacts.

The German Telephone Company is experimenting with a fiber optics telephone network that could replace the present copper wire network. A decision on replacing the current system with a fiber optics network is expected by mid-1986. The proposed telephone system could also use the fibers to provide television, telegraph and data transmission service.

While German fiber optics producers are accelerating research and development programs in the communications and defense data transmission fields, engineers at MBB are pursuing fiber optics applications in avionics and aircraft systems, with most work geared to accommodate the requirements of future combat fighter aircraft in the 1990's.

MBB is looking at a number of future applications for fiber optics in aircraft programs,including:

1. High speed data transmission, particularly for military aircraft, where weight, electromagnetic compatibility and vulnerability are important.

2. Redundant fiber optic systems to back up conventional data transmission line systems.

MBB has isolated one fiber that is nuclear blast resistant after testing a series of different fibers in a nuclear reactor. MBB is also exploring a number of other fiber optics technical programs, including:

1. Methods for splicing a broken fiber,

2. Measurement techniques to determine length of cables,

3. Methods to reduce energy loss in transmission process.

MBB's strategy in the fiber optics field is to develop avionics and aircraft applicable systems, while allowing fiber manufacturers to produce required equipment and technology.

2.5.3 ITALIANS MOVE CAUTIOUSLY INTO OPTICAL FIBER FIELD

The Italian industry is moving cautiously into fiber optics technology to insure that limited research and development funds are funneled into practical applications. Included in Italian efforts are space communications and aircraft avionics programs.

The careful approach in expanding Italy's basic and applied research base into defined case-by-case projects is calculated to maintain a steady level of activity in this high technology area. In this manner, specific future applications can be determined without dissipating finite resources on non-productive projects.

While worldwide research and development in fiber optics has yielded an enormous amount of data, practical use of light fibers must be better assesed before Selenia* commits large amounts of

company funds to any future program. Selenia is looking at a number of light applications (in addition to proven use in ground communications systems) including the following:

1. Integrated data distribution system for ships.
2. On board satellite communications system.
3. Radar subsystems.
4. Weapons communications field system.
5. Electronic warfare subsystems.
6. Air traffic control information systems.

While some Italian companies, such as Industrie Pirelli SpA, have overcome technical difficulties in producing optical fiber, others are still looking for applications in avionics and aircraft fields that would be cost effective.

All research for the next couple of years is expected to be directed at developing an Italian aircraft that incorporates fiber optics for on board applications, including a possible fly-by-light system.

*(Selenia is part of the STET (Societa Finanziaria Telefonica) group, a government holding company for telephone and electronics firms, and has access to basic fiber optics research of another STET controlled company, CSELT (Centro Studi e laboratori Telecommunicazioni SpA), located in Turin.)

A group of Selenia engineers have studied potential on board uses for several years. Since future satellites will be characterized by multifunctional multitransponder communications payloads, the engineers determined that mass, mechanical layout and increasing electromagnetic interference problems will create potential technical limitations on board the satellites. By considering low mass and EMI immunity of optical fibers, there

are two possible applications for satellite systems:

1. Signal routing with optical fibers instead of standard copper wire to reduce mass and EMI

2. In a regenerative repeater, information demodulation and processing at baseband frequencies could be combined with optical fibers to decouple and locate optimally the repeater sections within the spacecraft.

Selenia engineers have been partly successful in realizing the above envisaged applications. They are also exploring the use of fiber optics in communications and earth observation satellites, space stations, and scientific and military satellites.

Other applications under study by Selenia include optics that link satellite subsystems and payloads. Signal routing via optical fibers between command systems and payload systems could be carried out with the use of adapter boxes, which convert and reconvert electrical signals or pulses into optical signals or pulses and vice versa, or with a more integrated approach, where signals will be multiplexed or demultiplexed.

Electronica is concentrating on tailoring production of fiber optics systems for both military and civil applications, with on going systems programs limited to non-standardized requests. The company is currently working on an experimental shipboard data transmission system utilizing fiber optics for the Italian navy's Lupo class frigates, which links radar antennas to a ship board information distribution system. The company is also studying military fiber optics applications, including field line communications for military units. Its research wing has developed components and equipment for data transmission over

short and medium distances of up to 6 miles.

The approach to research in most of the Italian companies has been one of utmost caution. Each specific fiber optics application to a battlefield system is evaluated very carefully and justified before rushing into a costly and perhaps an inappropriate utilization program.

2.5.4 JAPAN'S FIBER OPTICS RESEARCH ENDEAVORS

Fiber optics applications in aerospace programs in Japan, which had a slow beginning because of little demand, are accelerating with application of optical devices in a flight simulator, and may lead to some airborne systems in a projected research aircraft within the next few years.

Fiber optics devices developed by the R&D division of Fujitsu, Ltd., were evaluated in a simulator for the projected short takeoff and landing (STOL) research aircraft being built by Kawasaki, which is expected to fly in 1986. Government funded research projects are underway exploring possible applications that include sensors, actuators, instruments, internal communications, and possibly, a fly by light technology utilizing a fiber optics system delivered by Nihon Electric Co. The system has been designed in a configuration that incorporates a star coupler with eight terminals, and current studies include a data bus control device designed for compatibility with the US MIL-STD-1533 specification.

The laboratory and Nihon Electric hope to develop an operational airborne system and to test it during later flight tests of the C-1 research aircraft being built by Kawasaki, probably by 1987. The laboratory is also pursuing work in laser gyro systems.

Nihon Electric Co.'s Research group expects to develop a fiber optics data bus operational hardware system within two or three years and laser gyro systems within four or five years.

Hitachi, Ltd. is working to apply fiber optics technology to a gyro system utilizing single-mode polarization fibers. The company also is working on feasibility studies of power transmission by fiber optics.

A fiber optics hybrid integrated circuit for use in a digital receiver in an advanced communication system has been developed by Tokyo-Shibaura Electric Co. (Toshiba) and delivered to the Japanese defense agency. The company also has completed a study of remoting of airport surveillance radar systems for the Ministry of Transport.

Efforts are also under way to utilize fiber optics links in new air defense warning systems now under development in a competition to replace the current Base Air Defense Ground Environment (BADGE) system within the next two years.

THE FIBER OPTICS INDUSTRY

3.1 USE OF FIBER OPTICS IN INDUSTRIES

The development of fiber optics technology was neither quick nor inexpensive. Why, then, go to the time and expense of developing a new system for conveying information, when a system of wires and microwave links is already in place? The answer is twofold. First, in many instances, fiber optic systems are more cost effective than other transmission systems. Secondly, fiber optics can perform many functions which are impossible to accomplish with other systems. All of this implies inherent advantages of fiber optics over metallic conductors. These advantages include:

- Complete electrical isolation,
- No possibility of short circuits,
- No spark or fire hazard,
- No electrical ground loop possibility,
- Immunity to RFI/EMI,
- Produces no RFI/EMI,
- Immunity to transient and lightning surge current,
- Extremely wide bandwidth,
- Smaller diameters,
- Lighter weight,
- No cross talk between fibers,
- Free from signal leakage and interference,

- Increased transmission security, and
- Use of plentiful, inexpensive natural resources.

To appreciate the importance of these advantages, consider how they affect the communications and industrial electronics industries.

Fiber optics depends upon the transmission of light, not electrical current or voltage. Therefore, even if the fiber is crushed or cut, there is no possibility of creating a spark. Thus, fiber optic systems are well suited for use in explosive environments such as mines, grain elevators, distilleries, refineries, and fuel storage sites.

Electrical signals transmitted over wires are susceptible to both electromagnetic interference (EMI) and radio frequency interference (RFI). Optical signals, on the other hand, are impervious to EMI and RFI. These characteristics are advantageous in data transmission applications where magnetic or RF fields may generate false data or cause system malfunctions. Optical links between computer peripherals, microprocessors, and computer mainframes, or within terminals, can eliminate such problems.

Electrical signals transmitted over wires generate electromagnetic fields. These fields provide a means for either secret eavesdropping or homing-in on the source. Both of these activities are serious security problems. Since fiber optic transmissions do no generate electromagnetic fields, they provide unmatched transmission security. The only way to steal information from a fiber optic transmission link is to physically tamper with the fiber, resulting in a signal loss that would be

immediately noticeable at the receiving end of the link. This aspect of fiber optics communication is very important to the military services, financial institutions, industrial organizations, and computer networks where profits, or even national security, depend upon secure communications channels.

Optical fibers have a much greater capacity for carrying information (bandwidth) than do coupler cables. Therefore, when costs are computed based upon utilization, optical fiber becomes very cost effective in high volume applications. For example, telephone companies can combine up to 24 two-way conversations on two pairs of copper wires. Using optical fiber, up to 672 two way conversations can be handled using only one fiber pair.

Optical fiber is also much smaller and lighter than copper wire. This is very important in many areas such as the telecommunications, automotive, aviation, and marine industries, as well as the military services. In telecommunications, fiber optic cable containing 144 individual fibers can handle 96,768 two way telephone conversations. Such a cable is about an inch in diameter and weighs about 6 ounces per foot. However, a copper wire cable with the same capacity would have a diameter of about 3 inches and weigh about 110 pounds per foot. In many urban areas, cable conduits are already filled to capacity and excavation for additional conduits would be very expensive, if not impossible. The solution is to remove the existing wire cable and replace it with fiber optic cable. This would not only reduce the present overcrowding, but leave room for major future expansion. Bulk and weight are also, of course, critical factors in

the design of automobiles, ships, aircraft, and space vehicles.

A primary incentive for use of fiber optics is immunity to electromagnetic interference (EMI), including radio frequency interference (RFI), noise arising from electromagnetic pulses (EMP's), and problems caused by ground loops [56]. The technology is also attractive because of high information carrying capacity, since present fiber cables have 10,000 times the capacity of comparably-sized copper circuits (lowering weight and space requirements) while frequently reducing installed cost [26,1]. Further, in environments where sparking or heating can create fire hazards, fiber optic communications offer opportunities to completely avoid electronics equipment [13].

3.2 DEVELOPMENT OF NEW COMPONENTS

To date, incorporation of fiber optics into systems has been generally limited by lack of available components. Basic as well as sophisticated devices are now becoming available, however, which should facilitate system design and implementation.

As an example, an intergated optical detector/preamplifier, developed by Vernon P. O'Neil of Motorola [55], simplifies receiver design and increases immunity to EMI and RFI. Engineers at Hewlett Packard have been working on integrated optical transmit/receive circuits [10]; the 5 V,125-nA elements now being produced are TTL-compatible, temperature and voltage compensated, operable with arbitrary data formats from DC to 15 Mb/s, and able to accommodate 55-db dynamic ranges. Similarly, General Electric has integrated a 100-mW 940-nm emitter and two photodetectors

into a package to be priced under $2 [34]. And Mitsubishi Electric is producing a range of fiber optic products, including semiconductor to fiber couplers, transmitter-receiver modules, and branches, switches, and attenuators [46].

Advanced devices now becoming available are illustrated by optical 100-Mbaud data multiplexers devised for airborne use [24]; units provide multiple redundant circuits in high capacity lightweight packages. More at the prototype level, but still offering potential for commercial use, an optical coupler developed at the San Diego Naval Electronics Laboratory Center may provide a practical way to tap bundles of multimode fiber optic cable. Also in this area, researchers at the University of Illinois report success with a failsoft single digit decimal multiplier; the arithmetic is implemented by the bundles of glass fiber guides carrying the optical signals [60].

3.3 INDUSTRIAL STANDARDIZATION

Standardization efforts are reaching fruition in fiber optics, removing another barrier to increased acceptance [21]. The Electronic Industries Association (EIA) has been active in this field since forming Subcommittee P6-3 in 1978. EIA standards on terminology and testing have already been approved and are being reviewed by practitioners; standards on design and performance are nearing completion [45]. The military has been involved in fiber optic standards as well. MIL standard 1678 is in use for cable testing and a document formalizing cable sizing has been proposed [25].

A number of private companies have been establishing in-house standards to ensure that their own fiber optic products can be effectively interconnected. Hewlett Packard, for example, has been working on a compatible line of terminal components, connectors, and cable for computer and other industrial systems; the firm has inter-computer links that operate at up to 10 Mb/s over distances to one km [30].

Opto Technology, Inc., of Wheeling, Illinois manufactures a fiber link transmitter-receiver pair typical of the standardization entering the fiber optics market. Their trademarked OP-TEC LINK OTD-500 fiber optic data link consists of a transmitter unit and a receiver unit, each only a half inch in height, constructed in a 24-pin DIP package with pins ready for soldering into a circuit board. This system is used for audio, video, and computer communications. The receiver is featured as a "low cost" fiber optic data unit of hybrid construction. By "hybrid" is meant that an amplifier is incorporated in the 24-pin chip. Opto Technology also makes packaged interrupters, optical switches that permit noncontact switching up to 10,000 operations per second. Such standardization of components has made possible the effective use of fiber optics in manufacturing operations for counting items leaving a production line, for instance.

3.4 INDUSTRIES INTERESTED IN FIBER OPTICS INDUSTRY

3.4.1 MILITARY AND AEROSPACE INDUSTRY

Fiber optic systems offer security as well as noise immunity, wide bandwidth, and small size. These factors have stimulated

considerable interest among military and aerospace researchers [44,66].

R. A. Greenwell of the Naval Electronics Laboratory Center in San Diego has demonstrated that fiber optics would often be a cost-effective alternative to wire for aircraft use [27]. Analyses based on two independent models showed that fiber optics offered lower total life-cycle costs while meeting or exceeding projected future requirements for EMI and EMP interference, as well as lightning strike vulnerability. As an example, fiber optic cables are considered appropriate for relaying commands and feedback signals between the cockpit and control surface sensors and actuators; mechanical flexibility facilitates installation in existing aeroframes [33].

Undersea, optical fibers have been evaluated for transmission of sonar signals within submarine hulls; F. C. Allard of the Naval Underwater Systems Center in New London Connecticut found EMI immunity sufficient to yield crosstalk rejection greater than 100 db, while elininating tonals in the sonar self-noise spectrum [2]. The US Navy has also used underwater fiber optic cables for communication between moored submarines and shore terminals. Distances over one km. are readily attained without repeaters and new low loss fibers are extending the distances [66]. Problems associated with the aquatic environment are being overcome. Systems have been implemented capable of withstanding 10,000 psi differentials and wide temperature ranges; using hermetic seals, the cables can operate for extended periods with no evidence of vapor diffusion [16]. The Navy is also investigating fiber optics

as a means of avoiding EMI susceptibility in its mine neutralization system [48].

The Italian destroyer, Ardito, has been retrofitted with a fiber optic system designed by the Central ab of Industrie [4]. The network, which is fully redundant, links 16 microprocessor-controlled remote terminal units. Communications include voice as well as analog, discrete, and synchro signals.

NASA has investigated the use of fiber optic cable to replace the 13,000 miles of conventional communication links at the Kennedy Space Center. Feasibility was demonstrated using frequency division multiplexing to take advantage of optical bandwidth and employing modular components for flexibility [5].

Some low cost, long life optical componments are finding their ways into radar systems. Arnold M. Levine of ITT reports that the stable transmission delay characteristics of optical elements may be utilized to provide high short term stability and reliability in circuits such as oscillators, phased array antennas, analog to digital converters, chirp curve comparators, and pulse generators [42]. Levine also indicates that techniques such as color multiplexing can be used to reduce the amount of cabling necessary in these systems.

Development activity in the military and aerospace sectors is continuing. For instance, the Air Force Avionics Laboratory has produced integrated optical circuits for use in neutron and gamma radiation environments. At Harry Diamond Labs, a fiber optic adapter has been designed to permit oscilloscope triggering by a light signal. According to Rudolph J. Prochazka of Harry Diamond

Labs, the device replaces the coaxial connector on the external trigger circuit of a conventional instrument and facilitates EMI studies in applications where wire cable can contaminate a shielded environment [62]. Harris Corp. has developed optical subsystems for military microwave and satellite communications; one such device involves use of fiber optics in a microwave integrated circuit antenna feed downconverter that eliminates the need for an interface waveguide [59].

An extensive fiber optics network complements other communications technologies in a command, control and communications system being developed to link missile sites for the proposed MX intercontinental ballistic missile program. The fiber optics links are a major element in the concept for an MX command, control and communications system being developed by General Telephone and Electronics Corp.'s Strategic Systems Div., Needham Heights, Massachusetts, under a $325.5 million five-year contract awarded by USAF last year. The award called for design, development and test of command, control and communications equipment in support of the MX program.

Under additional contracts, GTE is developing and manufacturing a fiber optic system to serve as a communications link between elements of the instrumentation and flignt safety support equipment being produced by Martin Marietta Aerospace.

Another contract from the Ballistic Missile Office provides for $4.5 billion to incorporates transmission capability in the fiber optic network for Martin Marietta to launch support equipment and provide for an automated sample data

instrumentation system that was designed by Rockwell International. Under the horizontal shelter concept for MX, the fiber optic system is planned to tie together an expected 4,600 shelters under the control of six manned Operations Control Centers which would have responsibility for monitoring equipment status, monitoring the physical security of remote sites, maintaining the system and responding to directives from the National Command Authority and Strategic Air Command.

A two-way fiber optic communication link being developed for the US Army by Hughes Aircraft Co., Los Angeles, could be the basis for low cost "lock on after launch" tactical missile systems that could be fired against unseen targets from concealed or sheltered launch sites. The optical link is immune to detection and enemy countermeasures and its real time image transmission capability meets Army needs for positive identification of targets in close-in environments where friendly and enemy troops may be comingled. The optical fiber, payed out as a missile flies, would carry information from a missile-born imaging target seeker to the launcher, where it would be portrayed to an operator who would designate a target for the missile against the imaging target.

One potential application for the optical link is in a successor to the Army/Hughes BGM-71A TOW antitank missile. TOW is a wire-guided missile, but the wire link between the missile and launcher lacks the bandwidth to carry imaging information in addition to the uplink commands. A TOW operator must maintain visual contact with a target throughout the missile's flight, and

thereby remains more or less exposed to enemy counterfire during this interval. Fiber technology provides an effective solution. It enhances launcher survivability in several ways, permits the launcher to operate behind the cover. Its immunity to detection and jamming enhances the value of the cover.

3.4.2 TELECOMMUNICATIONS INDUSTRIES

The telecommunications industry has been especially interested in fiber optics because of their high information capacity [20]. Early systems were limited because attenuation in the fibers required extensive use of repeaters to achieve long-distance communications. Low loss cable is now available that permits transmission distance of several km without amplification. Similarly, improvements in manufacturing technology are leading to longer fiber bundles, reducing requirements for couplings and splices. For instance, fiber bundles of 12.5 feet were considered state of the art in 1966, 44 feet was practical in 1968, and 1 km has been routinely achieved since 1978. Continuing length increases can be expected [29].

L.L. Campbell of Digital Communications Corporation has found land line trunking over low loss, small diameter cable to be especially cost effective [11]. In Canada, Celanese and General Motors are using fiber optics systems for intercity communications while Dow Chemical and Polysar are testing the concept [12].

System noise immunity has also been of interest, especially in telecommunications applications involving high electrical power levels. For instance, the British Central Electricity Generating

Board is installing a 20 km fiber optic cable to study its effectiveness for voice transmission between a power plant and a substation; the self-contained cable, sheathed with plastic and inserted in an aluminium tube, will carry administrative voice and protection information at rates of 34 Mb/s [18]. Similarly, Ontario Hydro is testing optical fibers for possible use in railroad switching yards [12].

3.4.3 SHORT HAUL COMMUNICATIONS INDUSTRIES

Factors favoring telecommunications are often applicable to short haul problems as well. Cable TV distribution is already a major high bandwidth short haul application [21]. H. Berkowitz of General Fiber Optics Inc. points out that step index fibers, which can transmit frequencies greater than 100 MHz, could readily accommodate existing single-channel video, audio, instrumentation, and computer interconnect applications [57].

A.D. Binder of ITT Electro-Optic Products Div. suggests that optical channels be considered for data buses since they could accommodate large numbers of users with high transfer rates and good intrusion security [33]. Links between process controllers and remote input/output devices could similarly take advantage of transmission speed and freedom from EMI [15]. Benefits might be especially significant in transmitting data between computers and numerically controlled machine tools, since strong magnetic fields are often present around such equipment [23].

Noise immunity can be significant for extremely short distance transmission as well. For instance, R.H. Harris of IBM

has proposed a data entry terminal with optical fibers running under each key [41]. When a key is depressed, a material with a high refractive index contacts the fiber and absorbs some of the transmitted light; photodetectors sense the reduction in intensity. Likewise, R. H. Ong of Honeywell has suggested using fiber optics for communication between a peripheral controller and a high speed line printer to reduce the number of cables and avoid false information caused by EMI and RFI. Mr. Ong of Honeywell has suggested using fiber optics for communication between a peripheral controller and a high speed line printer to reduce the number of cables and avoid false information caused by EMI and RFI. Mr. Ong indicates that transmission rates are limited only by the response of the optical components and the receiver [56].

3.4.5. INDUSTRIAL CONTROL APPLICATIONS

Fiber optics appears to be attractive for many control applications because of reliability and ability to withstand adverse environments as well as noise immunity. For example, Joseph Hansberry and Riccardio Vanzetti of Vanzetti, Inc. observe that insensitivity to high temperatures is creating interest in the metal working sector for use in controlling thermal processes such as induction heating, continuous casting, forging, hot stamping, pipe bending, die casting, laser treating and flame hardening [28]. Optical fibers also offer economy and reliability in situations where photoelectric detection is appropriate. Robert Fayfield of Banner Engineering Corp. believes that such

systems will simplify the implementation of systems to carry light from a source to a test object and back, for applications such as detection or counting under circumstances where size or environmental constraints have limited traditional sensors [22].

Westinghouse has developed a light fired thyristor for high voltage power switching. Optical fibers carry triggering light from the laser diode to the photosensitive thyristor. These units are less expensive than conventional devices and can reduce costs by avoiding noise-induced triggering [58].

MCCabe-Powers Body Co. has found fiber optic controls to be less expensive than those based on radio communications in fluid power systems, while maintaining electric isolation. The company has developed simplex and multiplex technologies for proportional and on-off applications [17].

3.4.5 AUTOMOTIVE INDUSTRY

The Automotive industry has shown interest in using optical fibers for vechicular monitoring and control. DuPont has been promoting its Crofon light guide for on board uses including light monitoring, dashboard illumination, signal transmission. Light weight, EMI immunity, ease of repair in the field, and durability are cited as the primary advantages. With multiplexing, especially, wiring harness complexity and cost may be significantly lowered [19].

A smoke alarm, developed in Switzerland by Cerberus, uses optical fibers for safety in hazardous areas and to prevent EMI-induced false alarms [35]. The light guides are used not only in

the detection circuits, but also for transmitting light from a centralized source to photovoltaic power cells on the individual units.

Smith Industries, Baingstoke, England, is developing a radiation pyrometry system incorporating a fiber optic data transmission unit. It is being developed as a means of providing a large amount of data on engine condition during operation, with accuracies significantly greater than those obtainable through traditional systems. As now constituted, it can provide accurate data on engine efficiency, thermal creep, thermal fatigue, rapid temperature fluctuations, blade cooling problems, temperature variations among various sections of a single unit, optimum flight profiles and optimum engine operating temperatures. The fiber optic guide, which connects to the rear of the pyrometer head, can accept temperatures of up to 300°C and carries the data to an area where avionics components can live.

MARKET-RESEARCH

4.1 FIBER OPTICS MARKETPLACE - A WORLD WIDE APPRAISAL

The market for fiber optics is a third bigger each year. Valued at less than $4 million in 1973 and $550 million this year, total worldwide sales are expected to reach $3 billion by the end of the next decade.

Not surprisingly, today's leading users are the U.S., Canada, the U.K., West Germany, France. The US alone accounts for 55 percent of fiber optics sales. Many observers feel sales in the U.S. are helped by the threat of nuclear war.

Scientists have long warned that a single 10 megaton nuclear explosion detonated 300 miles above Nebraska would create a burst of electromagnetic pulse (EMP) capable of shorting circuits and silicon chips across the country. The Department of Defense is moving to counteract such a possibility and the best way may be to replace copper lines with optical cable, which transmits light and is incapable of conducting excess electron energy. The AV8B aircraft that McDonnell-Douglas has wired with fiber optic systems is an indication of this trend.

A study available from Kessler Marketing Intelligence (KMI), a research group based in Newport, Rhode Island, agrees that the fiber optic market in the U.S., Western Europe and Japan will continue to grow, though at a much slower rate than the markets in the Carribean, South America, Asia and the Pacific. KMI

estimates the need for fiber optic systems in countries such as India, Australia, Taiwan and the Philippines will grow by an order of magnitude, from $ 21 million in 1983 to more than $210 million in 1989. Future market growth, KMI believes, will be spurred by technological advances such as:

1. Single mode transmission
2. Wavelength division multiplexing
3. Less expensive broadband switches
4. Passive couplers for sensors and local area networks
5. Integrated optical circuits for transceivers and optical logic
6. Increased fiber strength
7. Infrared transmitting fiber and components.

American production of fiber optic components should skyrocket from $59.1 million in 1980 to $408 in 1986 and $1.16 billion in 1990, reports Gnostic Concepts of Menlo Park, California. These components will be used to make up complete fiber optic cable systems with a value growing from $95.1 million in 1980 to $1.79 billion in 1990. The systems, in turn, will be part of overall programs whose total value will approach $4 billion per year by 1990.

Cable is said to be a 55 % segment ($ 27.6 million) of the total U.S. fiber optic component production in 1980. Production levels will climb rapidly to reach $211 million in 1985, then expand to $606 million in 1990. Optoelectronic modules will make up most of the balance.

The leading consumer of fiber optic cables will be telecommunication systems, moving up from a 21% share in 1980 to $458 million in 1990. Government applications, including military (the leading user in 1984), will climb to $214 million in 1990. Industrial, computer, and other applications will represent smaller markets.

Tumbling component prices in the next two decades will bring an explosion in demand for fiber optic systems. North American production will supply slightly more than half of this accelerating demand, led by such firms as Corning Glass Works, International Telephone and Telegraph Co., and Western Electric Co. The remainder will be supplied by competition in Japan, Western Europe and elsewhere, according to Jeff D. Montgomery, President of the Electronics Division of Gnostic Concepts, the Menlo Park, California, market researchers.

Montgomery likens the impact of future fiber optic systems on telecommunications to that of semiconductors on the vacuum tube in the 1960's. As spectrum congestion increases in the mid 1980's, limiting the expansion of satellite communications and terrestrial microwave systems, fiber optic links will begin to replace them and become a major market factor by 1990.

Lower charges for broadband transmission circuits made possible by fiber optics should rapidly expand markets for private fascimile networks, electronic mail, and video telephones. Fascimile transmission lines using copper cable are now measured in minutes, for example, but broader fiber optic bandwidths

should drop these to seconds and ultimately to tenths of a second.

Another spinoff of the market boom will be optical integrated circuits which are already being pursued by dozens of major laboratories with a cumulative total of about $50 million invested to date, including $15 million in federal funding. Major applications for these ICs, in addition to cable systems, will come in optical signal switching and data processing.

4.2 US OPTICAL FIBER MARKET OPENING FOR FRENCH FIRMS

Manufacturers of optical fibers in France are increasing their product lines while expanding entry into export marketplaces--particularly the U.S.

The companies comprising France's fiber optics industry have developed products including a number of fiber types, various kinds of connectors, and diodes and other components. These organizations are pursuing their projects individually, as well as with other French companies, and in conjunction with foreign firms.

One of France's fiber optics producers is Compagnie Lyonnaise de Transmissions Optiques (CLTO) which manufactures cables, fibers connectors and transmission systems. The company participated in development of a fiber optics radar link that has been in operation since 1980 at Nice Airport. Length of the link is 1,500 metres and it is used for transmission of a composite video signal. Advantages of the Nice Airport radar fiber optics link

over traditional wire links include elimination of electromagnetic interference problems and resistance to vibration.

In other work, CLTO began operation this year of a new optical fiber manufacturing facility that will be capable of producing 10,000 km of fibers per year and handle the fabrication of connectors and certain associated equipment.

The company is supported in its fiber production by an agreement with Corning Glass Works, Corning, New York, and with the patents and developments of the French Compagnie Generale d'Electricite (CGE) group with which CLTO is affiliated.

One French manufacturer that has established a foothold in the U.S. marketplace is Quartz and Silice, which manufactures a range of fibers for aerospace, biomedical and other uses. The organization is a fully owned subsidiary of the French Compagnie Saint Gobain. Quartz and Silice uses a plasma furnace and large preforms of pure synthetic glass to produce long, uncut fibers. Its plastic clad silica products are among the best available for aerospace applications because of their degree of radiation hardness. Approximately 85% of the company's production is for export and about 58% of this amount is sold to the U.S. market. Customers include various U.S. companies and the U.S. Naval Research Laboratory and Air Force.

Another French fiber producer is Fort, which has a staff of about 100 and exports approximately one half its total sales volume. In addition to its range of fibers, Fort also produces a fiber optics endoscope system that allows interior inspection of engines and areas of restricted volume. Fort endoscope systems

are used in a variety of inspection functions, including airline and military engines and non-destructive airframe examination. Fort also provides fiber optics cabling used in instrument panel illumination on Aerospatiale's AStar and Ecureuil helicopters.

In reviewing the fiber optics future, several executives at the French fiber manufacturers projected that aerospace applications will grow during the next several years as the technology's capabilities are further defined.

Additional work is expected to begin insuring that across the board standardization for fiber diameters, connectors sizes and other elements is achieved. This could open up lucrative markets in the Middle East and the Orient.

4.3 EXPORT OF U.S. FIBER TECHNOLOGY TO GERMANY

Market potential in Germany for optical fibers is expected to reach about $250 million in 1986 with production forecast at 600,000 km a year. Further growth to $400 million is expected by 1990 when production of 2 million km. of fiber is projected.

SEL and other West German fiber manufacturers are counting on significant import possibilities since a variety of already established national producers in all major Western nations will largely dominate their own markets and still have a surplus. U.S., French and British fiber manufacturers will meet local market needs, with little room for outside competition. Third World markets are limited because of a lack of requirements for the high technology systems. On the European Continent, German firms have started establishing collaborations with many U.S.

firms and an export of fiber technology to Germany is in the offing. About 90% of optical fibers in demand in 1990 will be earmarked for the West German Telephone and Telegraph (PTT) communications system.

The German telephone company is experimenting with a fiber optics telephone network that could replace the present copper wire network. A decision to replace the current system with a fiber optics network is expected by the end of 1985.

While German fiber optics producers are accelerating research and development programs in the communications and defense data transmission fields, engineers at MBB are pursuing fiber optics applications in avionics and aircraft systems, with most work geared to accommodate the requirements of future combat fighter aircraft in the 1990s. There are 40 specialized U.S. fiber technology engineers at MBB who are helping their German counterparts to work out the details of specialized aircraft systems. Since there is nothing available in the market for an aircraft fiber optics system, MBB is working on a number of programs to maintain its capability in the new field. MBB is trying to develop fiber optics that can be used like conventional wire on an airplane.

4.4 FACTORS AFFECTING U.S. SUCCESS IN THE WORLD FIBER TECHECHNOLOGY MARKET

Continued U.S. success in the world fiber optics market place will depend on sustained technological leadership and continued efforts to end trade-distorting practices in other producing

countries. The industry is urged to become actively involved in a trade association, in order to provide an "industry voice," through which to develop a coordinated industry position on issues of concern to manufacturers and to advise government officials of that position and its justification. This association could also gather data on the industry and serve as as information clearinghouse for fiber optics technology.

The possibilities for a joint consortium, along the lines of the Microelectronics and Computer Technology Corporation, should be explored. Also, the U.S. government should vigorously pursue its initiative in the U.S./Japan High Tech Working Group, give priority status on future agendas to bilateral problems in the fiber optics area, and establish a dialogue with European nations to pursue access to their telecommunications.

Other areas where the U.S. Government can promote the domestic fiber optic industry are in R&D, export controls, and in responding to foreign targeting practices. In R&D, the current tax credit should be extended, secure antitrust guidelines for joint research efforts defined, and provisions made for training and education to address long term skills problems.

In years to come, fiber optics may come to serve as a paradigm for economic development of high tech industries. The strategies of individual countries will be tested by the market explosion of the 1990's, and the winners in this arena will undoubtedly benefit in others.

TECHNICAL EDUCATION AT BERGEN TECH

5.1 OVERVIEW OF BERGEN TECH

The Bergen County Vocational-Technical Schools are a country-wide system having an annual enrollment of approximately 3,200 secondary students and over 12,000 adult students. In keeping with the philosopy of providing educational and technical training programs that meet current labor market requirements, the school administration is spearheading special programs in the area of electronic communications, fiber optics, digital electronics, computer programming and computer operations.

At Bergen Tech, comprehensive educational and technical training in high technology fields is designed to address:

1. The additional training needs for high school students who are currently provided training in basic electronics and electrical circuits, conventional drafting and machine shop practices;

2. The retraining needs of skilled technicians who are currently using the conventional methods.

5.2 HIGH TECH EDUCATION AT BERGEN TECH

There are very few, if any, programs at a vocational-technical level that address the technology of communications and fiber optics, CAD/CAM, robotics, pneumatics and hydraulics, programmable logic controllers, computers and microprocessors. To eliminate this deficiency, several levels of approach are needed in developing materials for this advancing technology. Operating

and equipment performance requirements for the vocationally oriented student, repair and troubleshooting systems for the technician, and the physics of components and systems for advanced technology students would begin to address this situation. The materials needed to implement a high technology of this type would include the determination of required learning experiences essential to each level of performance, the selection of equipment that would provide the means for learning the characteristics, application, and operation of the hardware and systems involved, and the recommendations for the curriculum development that would follow equipment testing, modifications, and applications to each of the three levels of learning.

Given below is a brief description of the various high tech programs at Bergen Tech.

1. In the area of CAD/CAM, developments in interactive computer graphics have enabled efficient, man-machine communications that make possible higher quality, greater productivity and lower production costs. The program in CAD introduces the student to the basic CAD concepts, operation of a CAD system, and preparation of engineering drawings using the computer. The CAM program introduces the student to the concept and operation of graphics computer systems used to produce part programming in the APT language for computer numerical control equipment.

2. The Robotics program is designed to develop an understanding of how a robotic device operates in terms of electrical and mechanical hardware. An advanced robotics course deals with voice synthesis, interfacing fundamentals, tactical sensing, vision systems and the application of robot systems in an industrial enterprise.

3. A program in Electronics Technology prepares students to assist engineers in prototype development and in testing procedures.

4. With the impact of high technology on industry, the use of computers for problem solving is gaining

importance. In order to meet the high tech challenge, the school has developed a Computer Science program which provides the balance between the understanding of the basic principles and concepts of computer science and hands on experience in the application of computer technology.

5.3 PERSONNEL TRAINING NEEDS IN COMMUNICATIONS AND FIBER OPTICS

Fifteen percent of the current American workers could lose their jobs by the end of the decade because of the advances in electronics and computer technology, according to the Congressional Budget Office (CBO). CBO also cited studies estimating that industrial robots could eliminate one to three million jobs in the near future and possibly up to seven million jobs by the year 2000. Another significant conclusion of the study was that these dislocated workers face a uniquely difficult employment situation which warrants special assistance through the provision of vocational and specialized training programs in high technology fields.

Before making an attempt to determine the training needs of personnel for high tech industries, it would be appropriate to provide a definition of a high tech industry. The U.S. Department of Labor, Bureau of Labor Statistics, defines a high tech industry as one in which engineers and scientists make up five percent more of the work force. The New Jersey Department of Commerce and Economic Development has chosen a broader definition: high technology exists in companies that are engaged in intellectual curiosity, systematic investigation and creativity which result in the development and commercialization of a sophisticated function or product. Employment in New

Jersey's high tech industries is divided into four broad areas: manufacturing, communications, computers, data processing, and research. A recent New Jersey state report points out that ten states, led by the sun belt area, attract more high tech industry than New Jersey. Needless to say, maintaining these jobs in New Jersey is very important to economic survival and progress. To encourage the development of high technology and the use of computers in communications, state officials are seriously considering programs for upgrading science and mathematics education, and for developing workers who are computer literate and communications proficient. A program to attract high tech companies to New Jersey and to foster the growth of new industries has been drafted by a panel appointed by Governor Kean.

The recent study by the State Department of Commerce and economic development showed that New Jersey ranked seventh in the nation in high technology employment between 1975 and 1980, with a 16.2 percent increase over those years. The biggest gain was found in the telecommunications industry. The study predicts that this industry will add at least 50,000 more jobs to the state's economy by 1986.

A report by Future Enterprises, Inc. notes that New Jersey is basically a state of mature industry that does not change much with time. To change this situation, the report warns the state to improve its vocational and postsecondary educational system and to gear its educational programs for the training and

retraining of workers in order to sustain the anticipated growth of the high-tech industry.

High technology occupations are characterized by heavy involvement with computers, by a systems oriented emphasis, electronics and by rapidly changing technical content. Technicians in high tech occupations must be able to use both the hardware and the software of computers and especially the newly developed microcomputers and communications systems. The complex systems embracing high-tech equipment may be composed of electrical, electronic, mechanical, pneumatic, hydraulic, thermal and optical devices, fiber optics and lasers. Therefore, technicians must have a broad technical background. Technicians with these interdisciplinary skills and knowledge can be prepared through well designed programs. They must be prepared with a broad technical and mathematical base so that they can continue to learn new techniques and to assimilate new information according to the changing technological environment. A broad understanding of basic principles in the various practices of high technology will guarantee that the technician has the flexibility to adapt quickly to the rapidly changing systems and computer technology.

High technology does not necessarily mean that machines will replace workers. It does mean, however, that the role of workers will change drastically. Many workers may already be obsolete in terms of job skills and knowledge of their changing vocations. They will need retraining.

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Engineering positions usually require at least a four year college degree; in many cases an advanced technical degree is now needed. Technologists and high level technicians need an A.A.S. degree or equivalent in technical (postsecondary) training. Technicians can be trained at a vocational-technical school level in communications, fiber optics and computers.

Many of the vocational and postsecondary programs wherein we currently educate and retrain technicians may be facing obsolecence. Educational institutions must move quickly and carefully toward restructuring their curriculums, redesigning their laboratories and retraining their faculty. Vocational and technical education today is facing the challenge of change. Its ability to respond properly to this challenge may determine its future role in meeting the needs of technical education.

5.4 CURRICULUM RECOMMENDATIONS

The preceeding chapters discussed at length the evolution of fiber optics technology, state of the art and the fiber optics industry across the globe. Research and developments over the last decade have resulted in reducing drastically the dispersion within the fiber core, improving dimensional control of the fiber core and cladding, reducing signal attenuation from several hundred db/km to a few tenths of a db/km, raising the tensile strength of the cable by more than an order of magnitude and developing components and connectors to facilitate installation and interconnections. All this has been done with an accompanying reduction in cost of the fiber cable from several dollars per

kilometers to twenty five cents per meter.

An integrated optical detector/pre-amplifier developed by Vernon P. O'Neil of Motorola is increasingly becoming common equipment in the communications and fiber optics industry. Hewelett Packard's optical transmit/receive circuits are making rapid forays into the communications industry because of their TTL compatibility, temperature and voltage compensation, and the ability to operate with arbitrary data formats from db to 15 Mb/s. It is not the intent of schools like Bergen Tech to train personnel to design such equipment. Engineers, trained by Institutes of Technology, are involved in the actual designing of the equipment. For the operation, maintenance and servicing of the equipment, it is not necessary to have personnel exposed to the curriculum of an engineering level. By imparting adequate skills in the field of electronics, communications and fiber optics, it is possible to develop manpower deft in the operation and maintenance of the type of equipment mentioned above. To substantiate the claim, an in-depth analysis of a typical job opening for a person trained at the technician level in a communications and fiber optics industry would be enlightening.

IBM has just completed a pilot project on an optical fiber trunk system. Encouraged by the success of the pilot, IBM is shortly commissioning a unit to develop data entry terminals with optical fibers running under each key. The basic elements of such a system are a light source, an optical fiber transmission system, and a receiver to convert the light pulses into electrical signals, and the shaping and reconversion of the

electrical signals into some usable form. The light source from the laser is electronically monitored, controlled and modulated. To operate the system delineated above requires a technician adequately equipped with skills in communications and fiber optics. The onus of designing the system shifts to the engineers whereas the maintenance of the equipment used in the system can be satisfactorily performed by a maintenance technician. It is precisely in these directions that schools like Bergen Tech can contribute in improving the quality of manpower needed by the high tech industries in the near future.

A review of the broad range of applications of fiber technology had been undertaken with an intent to provide practical approaches for teaching this technology at the vocational and technical level. In addition to reviewing the possible applications of fiber technology, an attempt was made to forecast the possible directions in which a technology of this nature would blossom in the near future.

An analysis of the fiber optics market revealed that the American production of fiber optics components should sky rocket to $408 million in 1986 and $1.16 billion in 1990. In years to come, fiber optics may come to serve as a paradigm for economic development of high tech industries. The strategies of individual countries will be tested by the market explosion of the 1990's and the winners in this arena will undoubtedly benefit in others.

Research on the fiber optics industry indicates that many workers may already be obsolete in terms of job skills and

knowledge of their changing vocations. In order to sustain the anticipated growth of the high tech industry, training and retraining of workers in the field of fiber optics technology is imminent.

Having analyzed the demand for skilled technicians, the next obvious step is to recommend a curriculum to meet the proficiency requirements of educational and technical skill levels in the areas of communication and fiber optics. The curriculum should be geared to prepare technicians to make an entry and to progress in high tech occupations. Such a curriculum should be well designed, well balanced and demanding.

A curriculum designed to meet these needs is presented in the appendix to this report. The curriculum is made up of two main parts:

1. an introductory course in electronic communications, and
2. a specialization area targeted to proficiency in fiber optics communications systems.

The overall goal of the basic/speciality sequence is to enable students to attain a basic level of expertise in the field.

5.3.1 PRE-REQUISITE TRAINING REQUIRED FOR THE PROPOSED CURRICULUM

The mathematical background requirements of electronic technicians depend on the type of jobs they hold. The proposed curriculum assumes that the student is well versed with the fundamentals of mathematics required for learning the electronics theory and for solving problems in electronics at the technical

level. The knowledge of the following topics is expected of the student intending to get the maximum benefit out of the proposed curriculum:

Algebra: Application of basic formulas, ratio and proportion, graphing of a function, solution of equations with two unknowns, radicals, quadratic equations, fractional equations, exponential functions and logarithms.

Trigonometry: Understanding of right triangle trigonometry, several basic identities, application of complex numbers, sine of an angle, cosine of an angle, law of cosines.

Suggested preparation in electronics : The concepts of current, voltage and resistance, Ohm's law, Watts's law, Kirchoff's laws, series and parallel circuits, fundamentals of AC and DC, a basic understanding of semiconductor diodes, diode circuits, and transistor circuit approximations.

A justification of the need to have the knowledge of the topics enumerated above, follows.

Many multiple load communications circuits have the loads connected in parallel. In a parallel circuit, the current in the main circuit divides and follows separate paths through the loads. Kirchoff's Laws apply to such circuits even when they contain more than one volatage source. Evaluation of important quantities like power dissipation, current and voltage across the load, necessitates the use of fractional equations and simultaneous equations with two unknowns.

Oscillators are used extensively in both transmitter circuits and receiver circuits. Feedback oscillator circuits incorporate an LC tank circuit. To evaluate the decrease of current in charging the capacitor, an understanding of the exponential functions is imperative.

In communications circuits, original signals require power or voltage amplification (gain) at the transmitter before transmission. The transmitted signal always involves power or voltage attenuation along the transmission line. Since the human ear responds to sound intensity in a logarithmic fashion, amplified or attenuated signals are described in terms

of logarithms. The power level in decibels is a description of the increase or decrease of power. Hence, a working knowledge of logarithms is essential to be at home with the decibel unit. In addition, the calculation of capacitance and inductance of two parallel transmission (power) lines involves logarithmic quantities.

Signal generation, transmission and reception involves the study of time-varying quantities. An understanding of the phase relationships among the time-varying quantities requires a thorough knowledge of the right triangle. The more one learns about the right triangle, the easier it will be to understand alternating currents.

Alternating currents are generated by rotating equipment. The expansion of the trigonometric functions to include angles greater than 90 degrees allows alternating currents to be described mathematically.

In evaluating the figures of merit of communications circuits, an analysis of transistor circuits is often necessitated. Any attempts to improve the performance of the transmitter circuits or the receiver circuits or the communications system as a whole, would be fruitless without an adequate knowledge of transistors, transistor circuits and suitable approximations of transistor circuits.

In teaching the concepts of communications and fiber optics technology at the technical level, an understanding of the mathematical concepts is emphasized. Much effort is made to avoid the mechanical 'plug in' approach. An analytical approach to problem solving is stressed. The approach is that which is used in actual on-the-job trade and technical occupations applications.

Integration of algebraic and geometric principles with trigonometry by careful sequencing and treatment of the material in the proposed curriculm will help the student to solve occupationally related problems.

In teaching the proposed curriculum at the vocat..ial level, a practical rather than an academic approach involving mathematics is taken. Derivations and formal proofs are not presented. Instead, understanding of the concepts followed by application of concepts in real life situations is stressed.

The proposed curriculum follows as an appendix to this report.

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APPENDIX

Course Outlines:

Introduction to Modern Electronic Communications (84 hours)
Modern Electronic Communications II (84 hours)
Introduction to Fiber Optics and Lasers (84 hours)

Bergen County Vocational-Technical Schools
200 Hackensack Avenue
Hackensack, New Jersey 07601
(201) 343-6000

COURSE TITLE:

INTRODUCTION TO MODERN ELECTRONIC COMMUNICATIONS I

Length of Course: 84 Hours

This project was funded during FY'85 under P.L. 94-482, Section 131, under a contract from the New Jersey Department of Education, Division of Vocational Education.

PREREQUISITES:

Algebra: Application of basic formulas, ratio and proportion, graphing of a function, solution of equations with two unknowns, radials, quadratic equations, fractional equations, exponential functions and logarithms.

Trigonometry: Understanding of right triangle trigonometry, several basic identities, application of complex numbers, sine of an angle, cosine of an angle, law of cosines.

Suggested preparation in electronics: The concepts of current, voltage and resistance, Ohm's law, Watts's law, Kirchoff's laws, series and parallel circuits, fundamentals of AC and DC, a basic understanding of semiconductor diodes, diode ciruits, and transistor circuit approximations.

UNIT I: INTRODUCTORY TOPICS

Unit duration: 6 hours

Unit Outline:

A. Definition of Communication; What Is Electronic Communication?

B. Importance of Electronic Communication, Noise, Noise Designation and Measurement, Noise Comparisions and Equivalent Specification Techniques

C. Information and Bandwidth

D. LC Circuits

E. Oscillators

F. Review Questions

Unit Objectives:

Upon completion of this unit, the student will be able to:

1. Refresh his knowledge about the various basic electronic components used in an electronic communication system.

2. Explain what noise means in the context of an electronic communication system and the important implications of noise considerations in the study of communications systems.

3. Comprehend that information can be sent electrically and explain why information transferred is closely related to the bandwidth utilized by the communications system.

4. Refresh his knowledge about the basic characteristics of LC circuits and various parameters associated with the LC circuits.

5. Review the working of an electronic oscillator and describe the specification parameters of an oscillator.

UNIT II: AMPLITUDE MODULATION - TRANSMISSION

Unit duration: 18 hours

Unit Outline:

A. What Amplitude Modulation Is All About; Amplitude Modulation Fundamentals

B. Percentage Modulation, Overmodulation, Calculation of percentage Modulation

C. Amplitude Modulation Analysis - A mathematical treatment of the AM concept

D. Circuits for AM Generation

1. Simple transistor modulator

2. High level modulators

3. Low level modulators

4. Linear integrated circuit modulator

E. Amplitude Modulation Transmitter Systems

1. Simple AM transmitter block diagram

2. Citizen's band transmitter

3. Monolithic LIC transmitters

F. Transmitter Measurements

G. Spectrum Analyzers and Special RF Signal Measurement Precautions.

H. Review Questions

Unit Objectives:

Upon completion of this unit , the student will be able to :

1. Explain the reasons why modulation is used in electronic communications.

2. Describe the concept of AM transmission and explain the various terms associated with AM systems.

3. Explain the basic circuits used for generation of AM signals.

4. Analyze basic AM transmitter systems and discuss the transmitter parameters.

5. Discuss spectrum analyzers vis-a-vis the communication systems.

6. State the differences between AM and FM.

UNIT III: AMPLITUDE MODULATION - RECEPTION

Unit duration: 12 hours

Unit Outline:

A. Receiver Characteristics

B. Amplitude Modulation Detection

1. Diode clipping

2. Diode detectors

3. Synchronous AM detection

C. Superheterodyne Receivers

1. Basic block diagram

2. Principle of operation

3. Frequency conversion and tuned circuit adjustment

D. Superheterodyne Tuning

1. Receiver tracking

2. Electronic tuning

E. Analysis of Superheterodyne Receivers

1. Broadcast band AM receiver

2. Image frequency

3. RF amplifiers, mixers, local oscillators, IF amplifiers

F. Automatic Gain Control

1. What is AGC?

2. The need for incorporating AGC in a receiver

3. Obtaining the AGC level

G. Complete AM Receiver Systems

H. Review Questions

Unit Objectives:

Upon completion of this unit, the student will be able to :

1. Logically envision a block diagram for a radio receiver.

2. Discuss the major characteristics of a receiver.

3. Explain why detection of AM signals requires a nonlinear electrical network.

4. Describe the superheterodyning concept and discuss the importance of a local oscillator in superheterodyne receivers.

5. Explain the purpose of automatic gain control and how this function is incorporated in a basic receiver circuit.

6. Discuss the major advantages and limitations of LIC superheterodyne receivers.

UNIT IV:

Unit Duration: 12 hours

Unit Outline:

A. Single Side Band Communications

1. The basic concept
2. Characteristics of SSB communication systems
3. Types of side band transmission
4. Advantages and disadvantages of SSB

B. Side Band Generation

1. The concept of balanced modulation
2. A Balanced modulator
3. Balanced ring modulator

C. SSB Filters

D. SSB Transmitters

1. Filter method of SSB generation
2. Phase method of SSB generation
3. Independent side band transmitters
4. LIC SSB transmitters

E. SSB Demodulation

1. Mixer SSB demodulator
2. A practical SSB demodulator

F. SSB Receivers

1. SSB receiver block diagram
2. Synthesized receiver

G. Review Questions

Unit Objectives:

Upon completion of this unit, the student will be able to :

1. Explain the different frequencies in a carrier amplitude-modulated by a single sine wave.

2. Discuss the advantages and disadvantages of SSB systems.

3. Logically envision block diagrams for side band generation.

4. Describe the various methods of SSB generation and discuss the merits and demerits of each method.

5. Logically envision the block diagram for a SSB receiver, explain the principle of operation of a SSB receiver.

UNIT V: FREQUENCY MODULATION - TRANSMISSION

Unit Duration: 18 hours

Unit Outline:

A. The Concept of Frequency Modulation and Phase Modulation

B. A Simple FM generator

C. Mathematical Analysis of FM

1. FM mathematical solution

2. Narrow band FM

3. Broadcast FM

D. Noise Suppression

1. FM noise analysis

2. Capture effect and preemphasis

3. Dolby system

E. Direct FM Generation

F. Indirect FM Generation

G. Phase Locked Loop FM Transmitter

1. Block diagram

2. Circuit description

3. Operation

H. Commercial FM Transmissions

I. Review Questions

Unit Objectives:

Upon completion of this unit, the student will be able to:

1. Define angle modulation and explain how it is different from FM.

2. Describe the effect of an intelligent signal's amplitude and frequency when it frequency-modulates a carrier.

3. Define the term 'modulation index' as applied to an FM

system.

4. Explain the meaning of 'center frequency' and 'frequency swing' in reference to FM broadcasting.

5. Explain the principle of FM generation.

6. Explain the operation of PLL FM transmission.

7. Discuss the merits of an FM communications system compared to an AM system.

8. Explain why FM is undesired in the standard AM broadcast band.

UNIT VI: FREQUENCY MODULATION - RECEPTION

Unit Duration: 18 hours

Unit Outline:

A. FM Receiver Block Diagram

B. Role of RF Amplifiers in FM Reception

C. FM Detectors

1. FM discriminator block diagram
2. Operation and principle of an FM discriminator
3. Slope discriminator
4. Ratio detector

D. Phase Locked Loop in FM Transmission

1. Block diagram of a PLL
2. PLL capture and lock
3. PLL FM demodulator

E. FM Receivers

1. Block diagram
2. Principle and operation of an FM receiver
3. Characteristics of an FM receiver
4. Figures of merit of an FM receiver

F. Review Questions

Unit Objectives:

After completion of this unit, the student will be able to :

1. Explain the purpose of a discriminator in an FM broadcast receiver.

2. Explain the circuit operation of a FM receiver.

3. Explain in detail how a PLL is used as an FM demodulator.

4. Discuss the differences between FM reception and AM reception.

5. Compare and contrast the figures of merit of an FM communication system and an AM communication systems

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COURSE TITLE:

MODERN ELECTRONIC COMMUNICATIONS II

Length of Course: 84 Hours

This project was funded during FY'85 under P.L. 94-482, Section 131, under a contract from the New Jersey Department of Education, Division of Vocational Education.

PREREQUISITES:

Algebra: Application of basic formulas, ratio and proportion, graphing of a function, solution of equations with two unknowns, radials, quadratic equations, fractional equations, exponential functions and logarithms.

Trigonometry: Understanding of right triangle trigonometry, several basic identities, application of complex numbers, sine of an angle, cosine of an angle, law of cosines.

Suggested preparation in electronics: The concepts of current, voltage and resistance, Ohm's law, Watts's law, Kirchoff's laws, series and parallel circuits, fundamentals of AC and DC, a basic understanding of semiconductor diodes, diode ciruits, and transistor circuit approximations.

Modern Electronic Communications I

UNIT I: COMMUNICATION TECHNIQUES

Unit Duration: 18 hours

Unit Outline:

A. Frequency Conversion Techniques

1. Double conversion, the concept and the block diagram

2. Up conversion, the principle and an exemplary up conversion system

B. Special Communication Techniques

1. Delayed automatic gain control

2. Auxiliary automatic gain control

3. Bandspread

4. Noise limiters

C. Metering the Received Signal Strength in a Communication Receiver

D. Frequency Synthesis

1. Basic frequency synthesizer block diagram, principle of operation

2. Low frequency synthesizers

E. Communications Transceivers

1. Principle and operation

2. FM communications transceivers

3. Block diagram and circuit analysis of FM communication transceivers

F. Review Questions

Unit Objectives:

Upon completion of this unit, the student will be able to:

1. Explain the difference between an FM stereo receiver and a communications transceiver.

2. Discuss the double conversion receiver and explain

its superior image frequency characteristics as compared to a single conversion receiver.

3. Discuss the advantages of delayed AGC over normal AGC and explain how it may be attained.

4. Explain the function of auxiliary AGC and give a means of providing it.

5. List some possible applications for 'metering' on a communications transceiver.

6. Discuss the relative merits of the synthesizers.

7. Describe the channel guard function in a communication transceiver.

UNIT II: DIGITAL COMMUNICATIONS

Unit Duration: 18 hours

Unit Outline:

A. Coding
   1. Concept of coding
   2. Advantages of coded signals
   3. Code noise immunity
   4. Common codes
   5. Morse Code

B. Code Transmission
   1. Code transmission details
   2. Two-tone modulation
   3. Principle of frequency shift keying
   4. FSK generation, FSK modem

C. Pulse Modulation
   1. Distinction between pulse modulation and AM and FM
   2. Pulse amplitude modulation
   3. Pulse width modulation
   4. Pulse position modulation
   5. Pulse code modulation

D. Multiplexers and Demultiplexers
   1. Principle of operation
   2. Frequency division multiplexing
   3. PCM/TDM repeaters

E. Sample and Hold Circuits

F. Delta Modulation
   1. Concept of Delta modulation

2. Merits and demerits of Delta modulation

G. Transmission of Digital Data

H. Telemetry

1. Telemetry block diagram

2. Typical telemetry system

3. Radio telemetry system

I. Review Questions

Unit Objectives:

Upon completion of this unit, the student will be able to:

1. Explain in what ways coded voice transmission is advantageous over direct transmission and cite possible disadvantages.

2. Explain the major disadvantage of the Morse Code for machine controlled communications systems.

3. Describe several methods of generating FSK and explain the principles involved in FSK.

4. Describe the key distinction between pulse modulation and amplitude or frequency modulation.

5. Describe a means of generating and detecting PWM, PPM, PCM.

6. Explain why a PCM TV transmission requires more quantizing levels than a PCM voice transmission.

7. Explain why Delta modulation is a truly digital system and contrast its differences from PCM.

8. List the basic functions performed by a complete telemetry system, and briefly explain them.

UNIT III: TRANSMISSION LINES

Unit Duration: 12 hours

Unit Outline:

A. Types of Transmission Lines

1. Two wire open line
2. Twisted pair
3. Shielded pair and coaxial lines

B. Electrical Characteristics of Transmission Lines

1. Principle and operation of a two-way transmission line
2. Equivalent circuit
3. Characteristics of transmission lines

C. Propagation of DC Voltage Down the Transmission Line

1. Physical explanation of propagation
2. Velocity of propagation
3. Delay lines

D. Nonresonant Lines

1. Definition of a nonresonant line
2. Definition of traveling waves
3. Traveling DC waves, traveling AC waves

E. Resonant Transmission Line

1. Definition of resonant transmission line
2. DC applied to open-circuited line
3. Incident and reflected waves
4. DC applied to a short-circuited line
5. Standing waves
6. Transmission lines as a capacitor or inductor

F. Standing Wave Ratio, Effect of Mismatch, Electrical Length of a Transmission Line

G. Smith Chart Introduction; Using the Smith Chart

H. Losses in Transmission Lines; Time Domain Reflectometry

I. Transmission Line Applications

J. Review Questions

Unit Objectives:

Upon completion of this unit, the student will be able to:

1. Define a transmission line and discuss, in general terms, the advantages and disadvantages of various types of transmission lines.

2. Draw the equivalent circuit for a transmission line, and explain the physical significance of each element.

3. Calculate the characteristic impedance of a transmission line using the Smith Chart.

4. Provide a physical explanation for the meaning of a line's characteristic impedance.

5. Explain the properties of nonresonant and resonant lines.

6. Explain the terms 'standing waves' and 'standing wave ratio' in reference to transmission lines.

7. Explain the disadvantages of a mismatched transmission line.

8. List and explain the various types of transmission line losses.

9. Explain the principle of time domain reflectometry and some uses for this technique.

UNIT IV: WAVE PROPAGATION

Unit Duration: 9 hours

Unit Outline:

A. Electromagnetic Waves

B. Physical Explanation of Wave Propagation

C. Electrical to Electromagnetic Conversion

D. Electromagnetic Wavefronts; Characteristic Impedance of Free Space

E. Ground and Space Wave Propagation

F. Sky Wave Propagation

1. Ionospheric layers

2. Ionospheric effects

3. Multihop transmission

G. Satellite Communications

H. Review Questions

Unit Objectives:

Upon completion of this unit, the student will be able to:

1. List the similarities and dissimilarities between light waves and radio waves.

2. Provide a definition of a wave front.

3. Explain the process of relflection of an electromagnetic wave.

4. Explain the difference between direct and reflected wave propagation.

5. List the steps that occur in the process of sky wave propagation.

6. Discuss the advantages that may be expected from the use of high frequencies in radio communications.

7. Explain what is meant by satellite communications and list reasons for its increasing popularity.

UNIT V: ANTENNAS

Unit Duration: 9 hours

Unit Outline:

A. Basic Antenna Theory

B. Hertz Antenna

1. Development of the hertz antenna
2. Impedance of hertz antenna
3. Antenna gain

C. Power Dissipation in the EMF's Produced by an Antenna

1. Radiation resistance
2. Effects of antenna length
3. Antenna efficiency

D. Antenna Feed Lines

1. Resonant and nonresonant feed lines
2. Delta and quarter wave matching

E. Special Purpose Antennas

1. Loop antenna
2. Ferrite loop antenna
3. Folded dipole antenna

F. Review Questions

Unit Objectives:

Upon completion of this unit, the student will be able to:

1. Explain what an antenna is and list the various figures of merit of an antenna.
2. Define antenna gain and beamwidth of an antenna.
3. Explain how the operating power of an AM transmitter is determined using antenna resistance and antenna current.

4. Explain what factors determine the resonant frequency of an antenna.

5. Explain the applications and advantages of various types of antennas.

UNIT VI: WAVEGUIDES, RADAR, AND FIBER OPTICS

Unit Duration: 18 hours

Unit Outline:

A. Comparison of Transmission Systems on the Basis of Transmission Lines and Antennas

B. Waveguides

1. Concept of a waveguide
2. Waveguide operation
3. Types of waveguides
4. Physical picture of waveguide propagation

C. Radar

1. Basic radar block diagram
2. Principle and operation of a radar system
3. Radar waveform and range determination
4. Radar system parameters
5. Doppler Effect, a principle utilized in many radar systems

D. Fiber Optics

1. A simple fiber optics communications system
2. Advantages of optical communication links over standard waveguides or copper conductors

E. Review Questions

Unit Objectives:

Upon completion of this unit, the student will be able to:

1. Discuss the relative merits and drawbacks of using antennas, waveguides and transmission lines as the medium for communication links.
2. Provide a definition of a waveguide.
3. Explain the difference between propagation in a

waveguide versus a transmission line.

4. Explain energy propagation down a waveguide.

5. Explain the principle and operation of a radar system.

6. Explain why a radar system has a minimum range.

7. Explain the function of each block in the radar block diagram.

8. List the basic elements of a fiber optic communications system and explain the advantages as compared to a more standard communications system.

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COURSE TITLE:

INTRODUCTION TO FIBER OPTICS AND LASERS

Length of Course: 84 Hours

This project was funded during FY'85 under P.L. 94-482, Section 131, under a contract from the New Jersey Department of Education, Division of Vocational Education.

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PREREQUISITES:

Algebra: Application of basic formulas, ratio and proportion, graphing of a function, solution of equations with two unknowns, radials, quadratic equations, fractional equations, exponential functions and logarithms.

Trigonometry: Understanding of right triangle trigonometry, several basic identities, application of complex numbers, sine of an angle, cosine of an angle, law of cosines.

Suggested preparation in electronics: The concepts of current, voltage and resistance, Ohm's law, Watts's law, Kirchoff's laws, series and parallel circuits, fundamentals of AC and DC, a basic understanding of semiconductor diodes, diode ciruits, and transistor circuit approximations.

Modern Electronic Communications I

Modern Electronic Communications II

UNIT I: REVIEW OF CONCEPTS IN OPTICS

Unit Outline:

A. Physics of Light

1. The optical spectrum
2. Geometric optics
3. Snell's law of reflection and refraction

B. Optical Components

1. Mirrors: concave, convex
2. Lenses: Lens action, biconcave and biconvex lenses, beam expansion and beam compression, beam shaping
3. Prisms

C. Radiation Measurement

1. Flux, incidence and exitance
2. Intensity
3. Solid angle and steradians

D. Photometry and Radiometry

Unit Objectives:

Upon completion of this unit, the student will be able to:

1. Determine the wavelength of any given optical frequency.
2. Determine the approximate "color" of any given visible wavelength.
3. Describe the following interaction of light and matter: reflection, refraction, absorption, diffusion.
4. Predict the reaction of light rays to the following optical components: mirrors, lenses, prisms.

5. Differentiate between the following optical concepts: energy, flux, incidence, exitance, intensity.

6. Appreciate what light is, how it propagates, how it reacts with matter, how it is measured and what is the relationship of light to the overall electromagnetic spectrum.

UNIT II: Why Fiber Optics?

Unit Outline:

A. Fiber Optics Fundamentals

1. Why fiber optics has evolved into something of significantly great importance
2. Concept of fiber optic communication
3. The Photophone - precursor of Bell"s telephone
4. Some modern concepts and ideas associated with fiber optics

B. Laser Definition

1. Basic principle of lasing
2. How a laser is produced
3. Laser in a fiber optic strand
4. Modulating a microwave carrier with a laser beam
5. Laser remote control system concept
6. Laser communication system
7. Some developments in laser technology

C. Advantages of Fiber Optics and Laser Communication Systems

Unit Objectives:

Upon completion of this unit, the student will be able to:

1. Explain the primary applications and advantages of fiber optics systems.
2. Discuss the various developments that lead to the evolution of fiber optics as a field of increasing interest and activity.
3. State the definition of a laser and expand the acronym LASER.

4. Discuss the potential of fiber optics and lasers in communication systems.

Suggested Experiments:

1. Demonstration of Voice Communication over a laser beam.

   Materials: 45-720 Laser video kit.

2. Measurement of speed of light.

   Materials: 45-720 Laser video kit.

3. Measurement of distances using a laser beam.

   Materials: 45-720 Laser video kit.

UNIT III: OPTICAL FIBERS: OPENING DOORS TO A NEW TECHNOLOGY

Unit Outline:

A. Optical Fiber Principles

1. Optical fiber development
2. Light propagation: total internal reflection, continuous refraction

B. Optical Fiber Construction

1. Types of optical fibers: single and bundled fibers
2. Fiber materials
3. Methods of propagation.

C. Fiber Optic Characteristics

1. Energy launching
2. Numerical aperture, source area, source radiation pattern
3. Radiation pattern versus fiber numerical aperture
4. Interface loss

D. Fiber Losses

1. Attenuation, dispersion
2. Summary of fiber losses

E. Fiber Optic Cables

F. Modern Technology uses Lasers to Manufacture Optical Fibers

Unit Objectives:

Upon completion of this unit, the student will be able to:

1. Describe the two methods of light propagation within optical fibers.
2. Calculate the critical angle of propagation and numerical aperture of a step index fiber.
3. Describe the three mode types available in optical

fibers.

4. List five general areas where the energy or information can be lost in a fiber optic link.

5. Describe six factors that contribute to attenuation within a fiber-to-fiber connection.

Suggested Experiments:

1. Determination of the linear attenuation of an optical fiber at various wavelengths

   Materials: KOP - 100 fiber optics kit, variable DC power supply, oscilloscope

2. Tracing the angular radiation or reception pattern of an optical fiber

   Materials: KOP - 100 fiber optics kit, variable DC power supply, oscilloscope.

3. Determination of the numerical aperture of the optical fiber from the reception pattern of the optical fiber.

   Materials: Same as in (2).

UNIT IV: FIBER OPTIC LIGHT SOURCES

Unit Outline:

A. Light Emitting Diodes

1. LED operation
2. LED construction
3. LED characteristics
4. LED biasing

B. Fiber Optics LED's

1. Fiber optics LED design considerations
2. Types of fiber optic LED

C. Laser Diodes, Fiber Optic ILDs

Unit Objectives:

Upon completion of this unit, the student will be able to:

1. Explain the operation and general characteristics of light emitting diodes and laser devices.
2. Describe the characteristics and advantages of coherent light.
3. Discuss the need of having fiber optic light sources.

Suggested Experiments:

1. Tracing the transfer function and emission pattern of a LED

   Materials: KOP - 100 fiber optics kit, variable DC power supply, Sine and square wave generator, oscilloscope.

2. Measurement of the electro-optic response time and of the junction and thermal time constants.

   Materials: Same as in (1).

3. Measurement of the time constants and sensitivities of a phototransistor and a photodiode. Measurement

of the linearity of a photodetector.

Materials: KOP - 100 fiber optics kit, variable DC power supply, square wave generator, oscilloscope.

UNIT V: FIBER OPTIC SYSTEMS

Unit Outline:

A. System Types

1. Data direction
2. System length
3. Networks

B. System Performance Factors

1. Spectral range
2. Bandwidth and rise time
3. Attenuation / km and total attenuation

C. Passive Interconnections

1. Connectors
2. Splices
3. Couplers

D. System Budgeting

1. Loss budgeting
2. Rise time budgeting

Unit Objectives:

Upon completion of this unit, the student will be able to:

1. Classify fiber optic communication systems using three parameters.
2. Describe eight different types of fiber optic communication systems.
3. Compare the performance of different systems using three performance factors.
4. Compare the relative merits of the different connectors and splices.

Suggested Experiment :

1. In this experiment, a distance measuring device is proposed. The displacement transducer uses two parallel optical fibers joined together and located at a variable distance from a diffusing surface. The receiving fiber, connected to a photodector, is used to collect and guide some of the diffused light energy. Consequently, the exctric from the detector varies proportionally with illumination on a distance range which depends upon the transducer characteristics and upon the actual optical power injected into the transmitting fiber.

   Materials: KOP - 100 fiber optics kit, variable DC power supply, oscilloscope.

UNIT VI: RECEIVERS

Unit Outline:

A. Photoelectric Effect

1. Photoemission, photoconduction
2. Photovoltaic action
3. Photoelectric materials

B. Photodetectors

1. Photoconductors
2. Photodiodes
3. Phototransistors

C. Photodetector Performance

D. Receiver Circuits

1. Data formats and transmission distances
2. Receiver types
3. Receiver qualities
4. Integrated circuit receivers

Unit Objectives:

Upon completion of this unit, the student will be able to:

1. Explain the photoelectric effect.
2. List the criteria for judging photodetectors.
3. Recognize the major photodetector types and understand their operation.
4. Describe the parts of a typical photodetector receiver circuit.
5. Use integrated circuit receivers.

Suggested Experiments:

1. Measure and observe the light dependent resistance of a photoconductive cell.

2. Measure the output voltage and current of a photovoltaic cell and calculate the cell output power.

3. Measure and observe the operating characteristics of a fiber optics communication receiver and transmitter.

Materials: Photoconductive cell, 6.3 Vat lamp, Solar cell, Transistor 2N2905, 2N2219 Fiber Optics Communications Receiver and transmitter.

UNIT VII: SIMPLE TELECOMMUNICATION APPLICATIONS OF FIBER OPTICS

Unit Outline:

A. Study of a Data Transmission System Using a Fiber Optic Link

B. Amplitude Modulated Fiber Optics Receiver

C. Amplitude Modulated Fiber Optics Transmitter

D. Frequency Modulated Fiber Optics Transmitter

E. Frequency Modualted Fiber Optics Receiver

Unit Objectives:

Upon completion of this unit, the student will be able to:

1. Tie all of the component parts together into an operational fiber optic link.
2. Describe an analog fiber optics transmission system.
3. Explain the advantages of a fiber optics communication system.

Suggested Experi ments:

1. A simple (but novel) optical transmitter to be demonstrated by using a torch and a vibrating metal diaphragm to modulate the reflected light, thus showing the connection of movement, sound and light intensity variations.
2. Transmission of analog signals - transmission of radio signals, high quality speech and music over an optical fiber. This includes a demonstration of the fact that audio signal is really passing down the fiber.
3. Transmission of Digital signals using one of the three digital interfaces: TTL, CMOS, RS232 Voltage levels.
4. Transmission of Morse Code.
5. Amplitude modulated data transmission system.
6. Pulse width modulated data transmission system.

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7. Pulse frequency modulation of voice over a fiber optics link.

   Materials: KOP-101 fiber optics kit (experiments 1 - 4), KOP-100 fiber optics kit (experiements 5,6).